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Validation and Sensitivity Analysis of a Crew Size Evaluation Method

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16. Abstract

Determining the crew complement needed on a ship is a complex and important process. The level of automation, type of cargo, and type of trade route all affect crew requirements on commercial ships. Technological change and economic pressure is fueling an increased interest in sailing with smaller crews. This in turn has prompted a critical look at traditional methods for determining crew size. The Coast Guard recently developed a computer model to evaluate crew size based on the shipboard tasks required to be performed. This tool, the Crew Size Evaluation Model (CSEM), is a task network model which simulates shipboard activities by specifying when each task occurs and assigning qualified crew members to perform them. The report describes the rigorous validation and sensitivity analyses used to evaluate CSEM. It was found that CSEM is able to provide a valid and flexible analysis of the effects of many different operational factors on crew size.

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METRIC CONVERSION FACTORS

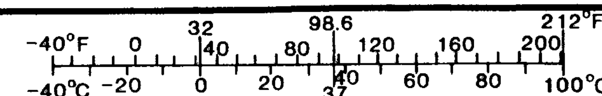
Approximate Conversions to Metric Measures

Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
in	inches	*2.5	centimeters	cm
ft	feet	30	centimeters	cm
yd	yards	0.9	meters	m
mi	miles	1.6	kilometers	km
		AREA		
in^2	square inches	6.5	square centimeters	cm^2
ft^2	square feet	0.09	square meters	m^2
yd^2	square yards	0.8	square meters	m^2
mi^2	square miles	2.6	square kilometers	km^2
	acres	0.4	hectares	ha
		MASS (WEIGHT)		
oz	ounces	28	grams	g
lb	pounds	0.45	kilograms	kg
	short tons (2000 lb)	0.9	tonnes	t
		VOLUME		
tsp	teaspoons	5	milliliters	ml
tbsp	tablespoons	15	milliliters	ml
fl oz	fluid ounces	30	milliliters	ml
c	cups	0.24	liters	l
pt	pints	0.47	liters	l
qt	quarts	0.95	liters	l
gal	gallons	3.8	liters	l
ft^3	cubic feet	0.03	cubic meters	m^3
yd^3	cubic yards	0.76	cubic meters	m^3
		TEMPERATURE (EXACT)		
°F	Fahrenheit temperature	5/9 (after subtracting 32)	Celsius temperature	°C

*1 in = 2.54 (exactly).

Approximate Conversions from Metric Measures

Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
mm	millimeters	0.04	inches	in
cm	centimeters	0.4	inches	in
m	meters	3.3	feet	ft
m	meters	1.1	yards	yd
km	kilometers	0.6	miles	mi
		AREA		
cm^2	square centimeters	0.16	square inches	in^2
m^2	square meters	1.2	square yards	yd^2
km^2	square kilometers	0.4	square miles	mi^2
ha	hectares (10,000 m^2)	2.5	acres	
		MASS (WEIGHT)		
g	grams	0.035	ounces	oz
kg	kilograms	2.2	pounds	lb
t	tonnes (1000 kg)	1.1	short tons	
		VOLUME		
ml	milliliters	0.03	fluid ounces	fl oz
l	liters	0.125	cups	c
l	liters	2.1	pints	pt
l	liters	1.06	quarts	qt
l	liters	0.26	gallons	gal
m^3	cubic meters	35	cubic feet	ft^3
m^3	cubic meters	1.3	cubic yards	yd^3
		TEMPERATURE (EXACT)		
°C	Celsius temperature	9/5 (then add 32)	Fahrenheit temperature	°F



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LIST OF ABBREVIATIONS

COI	Certificate of Inspection
CSEM	Crew Size Evaluation Model
IMO	International Maritime Organization
MSM	Marine Safety Manual
MSO	Marine Safety Office
NRC	National Research Council
STCW	Standards for Training, Certification and Watchkeeping

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EXECUTIVE SUMMARY

Objectives

Evaluating crew requirements is a complex and important process. The level of automation, type of cargo, and type of trade route all affect crew requirements on commercial ships. In the past, relatively simple rules and standards, such as those in the Marine Safety Manual, have successfully identified crew requirements. However, technological change and economic pressure make the traditional methods for evaluating crew requirements obsolete. These changes make it necessary to examine the fundamental contributions to crew requirements: the jobs and tasks that must be performed to safely sail a ship. Analysis of these shipboard tasks can provide a sound technical basis for assessing crew requirements.

In 1990, the National Research Council (NRC) recommended that government and industry establish safe ship crewing levels based on functional demands, including type of service and skills required. The use of formal analytical models for establishing safe crew levels and the resultant certificate of inspection (COI) was proposed. The basis for this formal approach is a shipboard task analysis, and verification of the analysis with logs of crew activities (NRC, 1990). Between 1994 and 1996, Battelle developed the Crew Size Evaluation Model (CSEM) to meet the basic requirements for the formal approach.

The project described in this report fulfills the NRC recommendations through the following activities and results:

- Collecting shipboard task analytic data from 4 tankers and 2 containerships (81 total mariners);
- Validating CSEM predictions regarding adequate crew levels, and;
- Applying the model to specific operational profiles such as port calls and work hour limits.

Findings

A comprehensive validation confirms CSEM's ability to provide a firm technical basis for crew size evaluation. CSEM meets or exceeds the initial requirements, suggesting that it can be used to examine a variety of operating procedures, new crew structures, watchkeeping schedules, the impact of new statutes, and emergency conditions.

A critical input to CSEM is task data. These data were validated through comparison of interviews with crew members, examination of scheduled maintenance logs, and shipboard observations. A comparison of workhour estimates, logs of mariners' work and sleep time, and patterns of work and rest shows that CSEM can capture differences between ship types and watch types to accurately predict workhours of mariners. These findings provide converging evidence that validates the ability of CSEM to evaluate crew requirements.

A series of sensitivity analyses indicates how a variety of factors influence the output of CSEM. Analysis of input data uncertainty shows that CSEM is relatively robust and not overly sensitive to small errors in task time estimates. However, larger errors in task times can undermine the accuracy of CSEM. Because the analysis demonstrated a strong relationship between the workhour demands of tasks and the effect of data uncertainty, the need to collect more precise data can be targeted to high workhour demand tasks.

Examining the internal model parameters showed that making CSEM's prediction of average sleep hours dependent on alertness, so that mariners do not sleep until they are tired, improves the model's predictions of time slept. This shows that the amount of sleep depends on factors beyond the total workhours.

The results also addressed potential simplifications to CSEM. Simplifying the task list undermines the accuracy and flexibility of CSEM. With the simplified task list, CSEM does not predict workhours as accurately, slightly overestimating crew requirements and failing to reflect the effect of watch and ship type. The poorer predictions, combined with the limited flexibility that accompanies a simplified task list, limits the utility of simplifying CSEM. Therefore, continued use of the more detailed task list is advised in order to retain the power and flexibility of CSEM.

The purpose of CSEM is to evaluate the impact of operational variables on crew requirements. Analyzing the effect of the frequency of port calls demonstrates that CSEM can be used to examine operational variables. CSEM is sensitive to the effect of increased port calls, showing the need for additional support for cargo operations and line handling as the port call frequency increases. These results support the conclusion that CSEM can successfully identify when operational variables create the need for additional crew.

Recommendations

The findings and conclusions support several recommendations for the future of CSEM. These recommendations fall into three categories: 1) analyses of operational variables to analyze crew size issues, 2) enhancements to CSEM, and 3) applications of CSEM to other Coast Guard initiatives.

The validation and sensitivity analyses suggest that CSEM is well suited to examine the effect on crew requirements of many issues and operational variables. CSEM can be used to examine a range of issues and the results can be summarized into guidelines. This approach generates guidelines that can be disseminated to Marine Safety Offices (MSOs) and Headquarters personnel. By incorporating these guidelines into the Marine Safety Manual (MSM) and other existing references, CSEM can effectively support the crew size evaluation process without burdening Coast Guard personnel with the need to learn the details of CSEM. This strategy provides the Coast Guard all the benefits and flexibility of CSEM without the burden of operating CSEM and analyzing its output.

The process of issue analysis begins by working with Headquarters personnel to identify key operational variables. Candidate variables include:

- Port calls.
- Engine room automation.
- Shore-based support for maintenance.
- Analysis of emergencies and crew incapacitation.

The flexibility of CSEM makes it possible to support other Coast Guard initiatives. Because CSEM can predict workhours, track task delays, and identify crew requirements, it may provide useful input to other Coast Guard projects. In particular, CSEM could screen alternate watchstanding schedules to evaluate their feasibility. The high cost of examining alternate watchstanding schedules onboard actual ships makes it important to precisely design any comparison. CSEM can help with this design process by screening out unworkable alternatives, and by maximizing the efficiency of expensive field experiments.

An important criterion for evaluating alternate watchstanding schedules is the effect on sleep. Given the logbook data collected as part of a previous study (Sanquist, Raby, Maloney, & Carvalhais, 1996), it is possible to examine the role of these factors and enhance CSEM's algorithms to better estimate sleep times. These changes will enable the Coast Guard to examine a broad array of interventions aimed at reducing fatigue and increasing vessel safety.

CSEM can be enhanced in two ways: 1) development of more precise measures of crew adequacy, and 2) expansion of the task database to include other types of vessel operations. Improving the measures of crew adequacy may involve a verification of the criteria for adding additional crew members. For example, a more detailed analysis of task delays might indicate that a delay of a single high-priority task, such as cargo loading, signals the need for an additional crew member. Developing more precise criteria would make the output of CSEM more interpretable and the results more consistent. CSEM can also be enhanced by increasing the task database. Currently the task data describe freighters and tankers; expanding this database to include other vessels, such as towing vessels, would enable CSEM to evaluate many more vessel types and issues. With task data describing other types of operations it would be possible to validate CSEM more extensively and address crew size issues, such as those that are specific to the towing industry.

Conclusion

This report shows that CSEM can provide a sound technical basis for crew size evaluation based on valid predictions of workhours and crew requirements. CSEM successfully addresses the NRC recommendation that calls for crewing levels based on the functional demands of ship operation. This report provides the foundation for CSEM, so that it can help guide long-term policy, examine specific crew size issues, support Coast Guard leadership within the International Maritime Organization (IMO), and enhance interpretation of U.S. Code.

1. INTRODUCTION

Evaluating crew requirements is a complex and important process. The level of automation, type of cargo, and type of trade route combine to affect crew requirements in a complicated manner. In the past, relatively simple rules and standards, such as those in the Marine Safety Manual, have successfully identified crew requirements. However, technological change and economic pressure are prompting changes that may make the traditional methods for evaluating crew requirements obsolete. These changes make it necessary to examine the fundamental contributions to crew requirements: the jobs and tasks that must be performed to safely sail a ship (NRC, 1990). This report examines how an analysis of shipboard tasks can provide a sound technical basis for assessing crew requirements.

Over the last several years, Battelle has worked with the Coast Guard to develop a method to evaluate crew requirements based on shipboard tasks. This work began with a feasibility study of a task-based method for evaluating crew requirements. Following this study, a task-based method called the Crew Size Evaluation Model (CSEM) was developed. CSEM evaluates crew requirements by simulating the activities that occur on a typical voyage. The model simulates shipboard activities by specifying when each task occurs and which crew members perform it. Just as on actual ships, crew members generally perform tasks during their scheduled watch or work period, but they may also be called upon to undertake tasks during overtime periods. High priority tasks, such as docking, might even interrupt their normal sleep period. Simulating shipboard tasks produces a timeline that shows when crew members stand watch, perform maintenance, and complete any other shipboard task. The simulation output identifies the hours that crew members work each day of the simulated voyage and any instances where tasks were delayed because crew members were not available. If tasks were not performed in a timely manner or if crew members worked excessively long hours, then the crew is considered inadequate. Figure 1 shows the wide variety of variables that a task-based method, such as CSEM, considers in evaluating crew requirements.

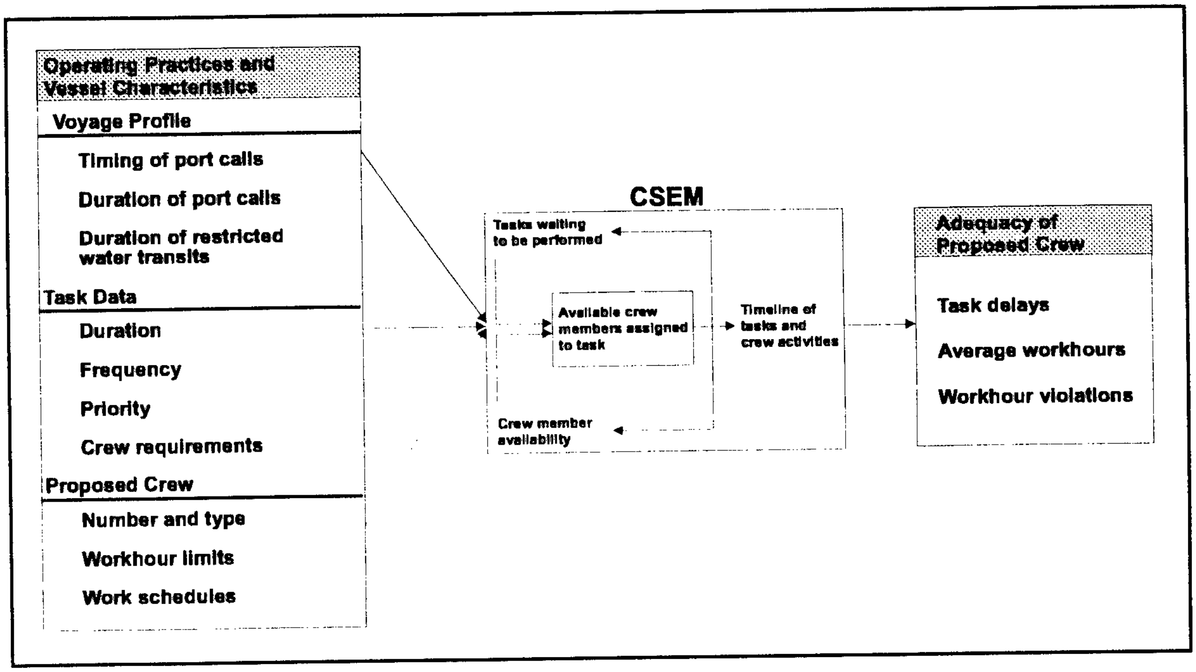

Figure 1. CSEM evaluates the effect of many different operating practices and vessel characteristics on crew requirements.

To address the complexities of crew size evaluation, the development of CSEM had the following objectives:

- Adapt to a wide variety of vessel types, cargoes, trade routes, and environmental conditions.
- Accommodate a variety of shipboard operating procedures and maintenance plans.
- Account for a variety of shipboard automation.
- Accommodate new statutes.
- Accommodate new crew structures and watchkeeping schedules.
- Consider emergency conditions and crew incapacitation.
- Record assumptions underlying model and data.
- Facilitate cost/benefit analyses of new rulemaking and foreign competitiveness.
- Facilitate Coast Guard-labor-management discussions.

Preliminary analysis of the frequency of port calls and alternate crew structures showed that CSEM has promise as a tool to evaluate crew requirements (Lee, Morgan, Rothblum, & Grabowski, 1995). In particular, analyzing the frequency of port calls showed that the workload of the Chief Mate increased with an increasing frequency of port calls. This is consistent with the Chief Mate's cargo handling responsibilities. These analyses showed that CSEM can address many crew size issues through an analysis of shipboard tasks.

The capabilities of CSEM, however, must be validated and explored before the model can be used with confidence. CSEM requires validation to ensure that the shipboard activities, workhours, and crew requirements it predicts match actual operating conditions. If CSEM's predictions do not match "actual conditions," it cannot be relied upon to produce accurate estimates of crew requirements. Validating CSEM requires a thorough evaluation of its predictions relative to shipboard activities and crew requirements. Once validated, it is important to explore the capabilities of CSEM to understand how broadly it can be used. Sensitivity analysis is a systematic method for exploring CSEM. Sensitivity analysis identifies factors that affect the accuracy of CSEM and shows how the model can be used to evaluate crew requirements. Sensitivity analysis can also be used to investigate the possibility of simplifying CSEM to better serve the needs of ship certification and maritime policy development processes. CSEM validation and sensitivity analysis provide the foundation for analyzing issues associated with crew requirements. This report describes the validation of CSEM and explores its capabilities through a sensitivity analysis.

2. OBJECTIVES

The goal of this study is to examine and improve CSEM so that it can produce reliable and accurate analyses of crew requirements. This goal depends on three specific objectives:

1. Validate CSEM's ability to evaluate crew requirements.

2. Investigate CSEM's sensitivity to factors affecting its output.

3. Demonstrate that CSEM can evaluate the effect of operational variables on crew requirements.

Validating CSEM's ability to evaluate crew requirements is an important prerequisite for using CSEM in any analysis. Validating CSEM ensures that it accurately reflects the factors that affect crew requirements. The validation process also identifies the conditions under which CSEM can be used and modifications that are needed to enhance its accuracy and capabilities. This process also reveals how accurately CSEM predicts shipboard activities, workhours, and overall crew requirements, and how key assumptions might affect this accuracy. Validating CSEM ensures that any subsequent analyses can be trusted.

After validation, the next objective is to examine the sensitivity of CSEM to model parameters and input data. This provides the necessary foundation for future analyses and data collection. For example, CSEM uses workhour violations to determine whether a crew is acceptable. Making workhour limits more restrictive likely will lead to increased crew requirements. For this reason, workhour limits are an important parameter of the model. If small changes in workhour limits lead to large changes in the required crew, then the selection of workhour limits becomes a very important step in the analysis process. A sensitivity analysis identifies the factors that have a particularly powerful effect on the output of CSEM. Identifying these factors can have great importance in the initial configuration of the model. The analysis can also identify the need to collect particularly accurate input data, as in the case where small errors in estimating particular task durations make a large difference in CSEM's predictions. Most importantly, the sensitivity analysis can also investigate potential simplifications of CSEM. One of the more important factors that might affect predictions of CSEM is the sophistication or complexity of the model and its input. A more complex model will likely produce more accurate results; however, a simpler model may make the evaluation process easier and less time consuming. A more complex model may be more flexible and able to address a greater variety of issues, compared to a simplified model. For example, CSEM could use a detailed task list consisting of hundreds of tasks to simulate shipboard activities, or it could use a simpler task list with only 20 to 40 tasks. The more detailed task list provides greater flexibility, but it is more difficult to collect and manage the data. By examining the effect of simplifying CSEM on its accuracy, it is possible to identify how CSEM can be simplified to support the crew size evaluation process most effectively. The sensitivity analysis of CSEM will provide a better understanding of the factors that influence its predictions.

The sensitivity analysis leads to the final objective of this study: To investigate operational variables—such as port calls—that have a particularly large influence on crew requirements. Analysis of operational variables demonstrates the ability of CSEM to support the crew evaluation process. Showing how port call frequency affects crew requirements paves the way for additional analyses that can guide Coast Guard policy.

3. METHODOLOGY

Preparing CSEM to analyze crew size issues requires three distinct activities: shipboard data collection, CSEM validation, and sensitivity analysis. As shown in Figure 2, each activity makes it possible to carry out the next. The shipboard data collection provides the foundation for evaluating the predictions of CSEM, as part of its validation. The shipboard data collection also provides the database of task information needed for the sensitivity analysis. The validation of CSEM and the data describing specific shipboard tasks provides the foundation needed for the sensitivity analysis. The sensitivity analysis uses the validated model and task data to show how CSEM output depends on factors such as data accuracy, model simplifications, and operational variables. Figure 2 shows how the data collection provides the foundation for CSEM validation, sensitivity analysis, and the future analysis of issues affecting crew requirements. Similarly, the issue analysis depends on a thorough validation and sensitivity analysis. The following paragraphs describe the general methods used in the data collection, CSEM validation, and sensitivity analysis.

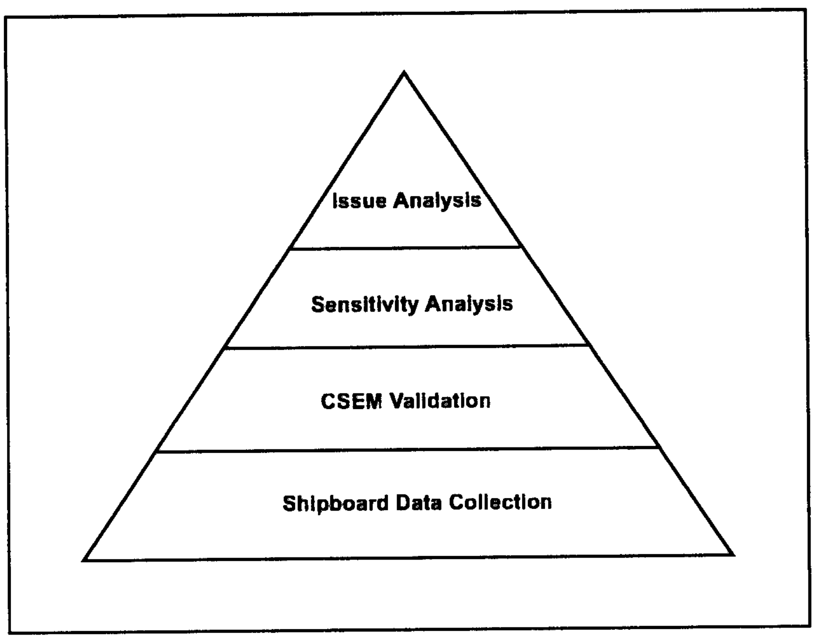

Figure 2. The data collection, validation, and sensitivity analysis, providing the foundation for issues analysis.

3.1 Shipboard Data Collection: What Are the Activities Aboard Commercial Ships and How Do They Contribute to Crew Requirements?

The goal of shipboard data collection is to document activity aboard tankers and freighters and collect task data for CSEM validation and sensitivity analysis. Addressing CSEM validity requires information concerning the particular events, such as port calls, that affect crew requirements, timelines of shipboard activities, typical hours worked, description of peak work periods, and other factors that disrupt routine shipboard work schedules. This information provides a point of comparison for CSEM predictions. Specific task data provide the input to CSEM needed for the sensitivity analysis and future use. These data include the task duration, frequency of occurrence, and crew requirements. Many shipboard tasks depend on the type of ship or route. For this reason, ship and voyage characteristics are recorded to identify the influence of operating conditions on crew requirements and shipboard activities. Documenting ship characteristics and shipboard activity provides the basis for the validation and sensitivity analysis.

Several data collection approaches were needed to document shipboard activities. The shipboard data collection included structured interviews, observations, analysis of planned maintenance logs, and logbook data. Structured interviews provided a very efficient way to collect a large amount of information about general shipboard activities and specific tasks; however, a combination of response bias and potential misunderstandings make it useful to augment the structured interviews with data from other sources. Logbook data, such as that collected by Sanquist et al. (1996), helped augment the work and sleep information gathered during the interview. Direct observations served as a useful complement to interviews to document general shipboard activities and specific task data. Similarly, examining planned maintenance logs helped verify specific task data, such as the task duration and frequency of occurrences estimated by the mariners. Using several data collection approaches avoided the limitations encountered with any one approach.

Data were collected by teams of two researchers who visited each ship for 5 to 7 days. During this time, they conducted two interviews with each participating crew member. A total of 81 mariners were interviewed, providing a representative sample of crew members. Each interview lasted approximately one hour. The first interview covered several topics related to work schedules and fatigue. This interview began with a set of questions about the mariner's background and then moved into a series of questions that identified activities over a typical day. Mariners were then asked to describe factors that might disrupt or extend their normal work periods, scheduled overtime, and sleep. The interview concluded with a set of questions about total hours worked and slept each day and factors that lead to excessive fatigue. Thus, the first interview provided a broad range of information to support the validation of CSEM.

The second interview focused on the specific tasks performed by each mariner. During this interview, mariners were introduced to the task list and then asked a series of questions about each task (Appendix A includes the entire task list). For each task, these questions requested the duration, frequency, crew requirements, and priority. Each mariner was also asked which tasks are performed at the same time and which tasks can be interrupted or passed to other crew members. This interview provided the input for CSEM, which included data for all tasks performed aboard tankers and freighters.

Six ships were visited for the data collection; two were container ships and four were tankers. Table 1 summarizes the data collected from each ship, and Table 2 shows the number and types of crew members who participated in the interviews.

Table 1. Ships involved in the data collection.

Ship number	Ship type	Route	Data collected
0	Tanker	Ocean-going	Observations and preliminary data
1	Freighter	Ocean-going	Observations, general shipboard activity, specific task data
2	Tanker	Coastwise	Observations, general shipboard activity, specific task data
3	Tanker	Coastwise	Observations, general shipboard activity, specific task data
4	Freighter	Coastwise	Observations, general shipboard activity, specific task data
5	Tanker	Ocean-going	Observations, general shipboard activity, specific task data

Table 2. Crew members involved in the data collection.

	Ship Number					
Crew Position	**1**	**2**	**3**	**4**	**5**	**Total**
Master		1	1	1	1	4
Chief Mate	1	1	1		1	4
2nd Mate	1	1		1	1	4
3rd Mate	1	1	2	1	1	6
Chief Engineer		1		1		2
1st Engineer	1	1	1	1		4
2nd Engineer	1	1		1	1	4
3rd Engineer		1	2	1		3
Chief Electrician	1			1		2
Radio Officer	1	1		1		3
Boatswain	1	1	2	1	1	6
Pumpman		1			1	2
Oiler					1	1
AB Seaman	3	2	2	3	5	14
QMED		2		2		4
Utility		1	1			2
Chief Steward, Steward	1		1	1	1	4
Chief Cook, Cook, Asst. Cook	2			2		4
Messman			1	2	2	5
Cadet	2			1		3
Total	**16**	**16**	**14**	**21**	**16**	**81**

3.2 Model Validation: Can CSEM Evaluate a Proposed Crew Accurately?

The purpose of the model validation is to determine if CSEM provides an accurate analysis of crew requirements. Without a thorough analysis of CSEM's accuracy, the model could produce misleading results. For this reason, CSEM must be evaluated before it can be used to analyze the factors affecting crew requirements.

CSEM validity can be defined as the match between its predictions and the actual crew requirements. Most broadly, this means that the crew specified by CSEM must match the actual crew required to safely sail the ship. Considered in more detail, this means that CSEM must accurately generate predictions of the average workhours and the number of workhour violations. At the greatest level of detail, CSEM should simulate the timeline of activities as they occur onboard the ship. Thus, a comprehensive definition of validity considers CSEM accuracy from several perspectives, each addressing a different aspect of crew size evaluation. Lee and Sanquist (1992) provide a more detailed description of the validation process. The following five approaches form the core of the validation process:

1. Model scope validation: Does the model cover all the major factors affecting crew requirements?

2. Conceptual approach validation: Do the underlying ideas of the model reflect actual shipboard activities?

3. Implementation validation: Is the conceptual approach accurately translated into the computer-based model?

4. Input data validation: Are the inputs to CSEM accurate? For example, does the estimate of task duration match the time it takes to perform the actual task?

5. Model output validation: Does the output of the model accurately mimic crew activities, workhour averages, and crew requirements?

The first approach to validating CSEM clearly defines its capabilities. Validating the model scope involves comparing the general capabilities of CSEM to the range of issues that affect crew requirements. This comparison indicates the bounds of how CSEM can be used and it may indicate the need to include new capabilities.

Validating the conceptual approach involves comparing the method used to simulate shipboard activities to the process, priorities, and traditions that actually govern shipboard activities. This comparison identifies mismatches between how CSEM simulates shipboard activities and calculates workhours and the factors that actually guide shipboard activity and determine when people work and rest. Changing CSEM to eliminate these mismatches will enable it to simulate shipboard activities and estimate workhours more accurately.

Validating the implementation involves verifying that the conceptual approach has been accurately translated into computer logic. This can be done by testing individual software modules and examining the results of a series of test scenarios. The outcome of this process is a computer model that accurately reflects the conceptual approach.

Validating the input data involves examining the task list and screening task data to ensure that they accurately reflect shipboard activities. This process ensures a comprehensive task list and task data that are representative of several types of ships.

Validation of the CSEM output is the final test of its validity and shows how well CSEM can predict shipboard activities, workhours, and overall crew requirements. This step in the validation process involves comparing the timeline of activities, average workhours, and predicted crew requirements to those observed on actual ships. Matching the output of CSEM to observations of actual ships identifies how well CSEM can simulate the factors that influence crew requirements. This comprehensive validation process clearly specifies the purpose of CSEM, its assumptions, and its accuracy, providing a firm foundation for crew size evaluation.

3.3 Sensitivity Analysis: What Factors Affect the Accuracy of CSEM and the Predicted Crew Requirements?

The purpose of the sensitivity analysis is to investigate the factors that have a particularly powerful effect on the output of CSEM. The sensitivity analysis is important because it explores the capabilities and limits of CSEM, providing a better understanding of how it can evaluate a proposed crew. The sensitivity analysis shows how input data, model parameters, and operational variables affect predicted crew requirements. Understanding how the accuracy depends on factors, such as the precision of task time data, can focus future data collection efforts. Understanding how CSEM parameters, such as task allocation algorithms, affect its output can guide future model enhancements. Understanding how operational parameters, such as the frequency of port calls, affect its output can provide the foundation for future analysis of crew-size issues. A better understanding of CSEM can guide its use by identifying: 1) factors influencing its accuracy, 2) its range of use, and 3) important issues that affect crew requirements.

Sensitivity analysis can be defined as the systematic examination of how incremental changes to a variable of interest affect the results of a CSEM analysis. These changes can include errors in the input data, such as inaccurate estimates of task durations. Changes might also include variations in the way CSEM evaluates crew requirements and operational variables, such as port call frequency. The relationship between changes in a variable, such task durations and crew requirements, can be quantified to define the characteristics of CSEM. The sensitivity analysis of CSEM examines how the following factors affect the evaluation of crew requirements:

- Internal model parameters and algorithms.

- Input data uncertainty.
- Simplifying the input data.

Each analysis examines CSEM from a different perspective. Analysis of internal model parameters and algorithms involves changing the rules or processes that simulate shipboard activities and recording the effects. This analysis identifies how sensitive CSEM is to changes in the way shipboard activities are simulated. The less sensitive CSEM is to these changes, the more likely it will produce results that apply to a wide variety of situations. Analysis of input data uncertainty shows how CSEM output depends on the task durations when they are systematically increased to mimic the effect of overestimating task durations. This analysis identifies tasks that merit additional data collection because they have a large effect on CSEM output. The analysis of potential simplifications to the input data examines how the output of CSEM changes as the task list is simplified. If simplifications to the task list do not affect the output of the model, then a simpler task list could be used for future analyses. Together, the elements of the sensitivity analysis show how CSEM responds under different conditions. This analysis highlights useful applications, potential simplifications, and key factors affecting crew requirements.

Each sensitivity analysis takes a baseline condition, makes systematic changes, and records the effects. A uniform baseline makes comparisons between analyses meaningful. The characteristics of the baseline condition include:

- CSEM algorithms and characteristics as validated.
- A crude oil tanker during a 7-day voyage, with a port call at the beginning and one at the end.
- A fully manned, steam turbine engine room.
- Crew of 24, including a watchstanding Chief Mate.

3.4 Analysis of Operational Variables

The purpose of CSEM is to support analysis of crew size issues through analysis of operational variables. Using CSEM to examine the effect of operational variables provides a technical basis for evaluating how crew requirements depend on factors, such as workhour limits, frequency of port calls, and the level of automation. In this report, we examine the effect of port calls to demonstrate how CSEM might support the analysis of crew size issues. Analysis of port call frequency involves recording the effect of increasing the number of port calls. This will show how crew requirements depend on this key operational variable. The analysis of port call frequency shows how CSEM can examine important crew size issues. Using CSEM to conduct similar analyses on other variables can help to clarify crew size issues.

4. FINDINGS

The findings address CSEM validation and the sensitivity analysis and analysis of operational variables. This section begins with a description of the outcome of the five approaches to validation described in section 3.2. These results document the ability and limits of CSEM to evaluate crew requirements accurately. They also show how CSEM was enhanced to increase its validity. The findings of the sensitivity analysis follow the description of the validation, and describe the range of CSEM applications and potential simplifications. The final section describes the analysis of an important operational variable: the frequency of port calls.

4.1 Model Validation

The five approaches to CSEM validation show that CSEM can be relied upon to evaluate crew requirements. These results demonstrate the broad capabilities of CSEM by showing that it addresses critical crew size issues. The results also demonstrate that CSEM can accurately simulate the sequence of shipboard tasks that might lead to workhour violations and excessive fatigue. The detailed findings of the individual validation techniques highlight the broad range of issues CSEM is suited to address, identify potential improvements to CSEM, and demonstrate the reliability of CSEM.

4.1.1 Validation of the Scope of CSEM

Comparing the capabilities of CSEM to the factors affecting crew requirements identifies the range of issues CSEM can address and potential improvements that could extend its capabilities. Validating the scope of CSEM answers the question: Can a task-based approach to simulating shipboard activities consider the full range of factors that affect crew requirements?

Validating the scope of CSEM involves comparing the model's capabilities to the broad issues affecting crew requirements. The purpose of CSEM is to evaluate a potential crew complement to ensure that it is sufficient to manage a ship. To achieve this objective, CSEM must address the factors by which an inadequate crew might undermine safety. An inadequate crew can undermine safety in three ways. First, crew members might not have the qualifications needed to perform assigned tasks. Second, the crew might not contain enough crew members to perform shipboard tasks in a timely manner and within workhour limits. Third, crew members might be exposed to workloads and schedules that cause them to become dangerously fatigued. Figure 3 indicates how CSEM addresses these three key issues that govern crew requirements. This figure shows that CSEM can evaluate the ability of a proposed crew to perform tasks in a timely manner without exceeding workhour limits. CSEM also partially addresses the issues of task assignment and fatigue.

General Capabilities and Issues	Ability to Address Issue	
Perform tasks in a timely manner without exceeding workhour limits	Partial	Complete
• Examine a variety of operating procedures		
• Examine new crew structures and watchkeeping schedules		
• Accommodate new statutes		
• Consider emergency conditions		
• Record assumptions underlying data		
Tasks assigned to qualified crew members	Partial	Complete
• Identify qualifications required for shipboard tasks		
• Specify crew types required to perform task		
• Specify certifications required to perform a task		
Work schedules to avoid excessive fatigue	Partial	Complete
• Calculate duration of rest periods		
• Estimate average hours slept		
• Estimate alertness over the day		

Figure 3. The scope of CSEM, shown by its intended ability to address various issues influencing crew requirements.

Figure 3 shows that CSEM is a flexible tool, the scope of which completely addresses several critical elements of crew size evaluation. In particular, CSEM can examine the effect of a wide range of operating procedures and crew structures. Differences in operating conditions that CSEM can consider include the use of shore-based maintenance workers, the availability of assistance for cargo handling, and the frequency and duration of port calls. This flexibility also accommodates new statutes and analysis of potential regulatory changes. For instance, CSEM can address workhour limits other than those imposed by the OPA 90 legislation, such as a workhour limit of 28 hours in a 48 hour period. CSEM is also able to consider a range of emergency conditions. By specifying the tasks and activities associated with emergencies CSEM can evaluate their effect on other operational demands, such as watchstanding, and the ability of the crew to respond to the emergency in a timely manner. To document the analyses, CSEM includes the ability to annotate the task data with explanations that describe the assumptions underlying the data. CSEM's ability to examine the broad range of issues related to crew size evaluation helps to validate the scope of CSEM.

CSEM defines crew qualifications indirectly by linking the qualifications to the crew type, such as Master, Chief Mate, or Chief Engineer. CSEM defines the qualifications of each crew type by the tasks that they can perform. For example, the qualifications of the Chief Mate are defined by the tasks, such as cargo operations, to which a Chief Mate is assigned. As new crew types evolve as a result of technological and regulatory changes, it may be difficult to assume a particular crew type is capable of performing any particular task. Specifically, the advent of the Standards for Training, Certification and Watchkeeping (STCW) changes to crew designations, may make it difficult to assign tasks to crew types. Addressing this difficulty does not require changes to CSEM as much as it requires additional data collection to confirm that each crew type can perform the tasks that have been assigned. For example, if a new crew type is created that has both engine room and bridge watchstanding responsibilities, it may be difficult to identify which engine room and deck tasks this crew type is qualified to perform. It is unlikely that this new crew type would be qualified to perform all the tasks previously performed by the mates and the assistant engineers. CSEM can analyze the effect of introducing this new crew type only after identifying the tasks the new crew type can perform. CSEM can then verify that the proposed crew includes crew members who are qualified to perform all the shipboard tasks (see Appendix A for detailed task definitions). To directly address the license and certifications of crew members, CSEM would need to be modified.

Like the issue of crew qualifications, CSEM only partially addresses the issue of fatigue. CSEM evaluates crew requirements by matching crew to tasks in a way that mimics actual shipboard activities and then calculates workhours. A crew is judged to be adequate if it complies with workhour limits and is able to perform tasks in a timely manner. Compliance with workhour limits only implicitly considers fatigue. A proposed crew might comply with workhour limits and yet some crew members might experience excessive levels of fatigue due to the timing and distribution of sleep periods (Sanquist, et al., 1996). As a first step in addressing this issue, CSEM now includes a simple model of alertness. Based on the work of Akerstedt and Folkard (1995), this model predicts alertness based on the time since awakening, length of sleep, and circadian variations. This simple model of fatigue might enable CSEM to examine some of the potential problems with fatigue directly, rather than indirectly through workhour violations.

Validating the scope of CSEM highlights some important assumptions and defines the limits of CSEM. The assumptions associated with CSEM analyses include:

- Levels of fatigue can be identified by violations of workhour limits and a simple model of fatigue. A crew is sufficient if it can perform tasks in a timely manner without exceeding workhours and without reaching excessive levels of fatigue, as measured by the simple model of fatigue included in CSEM.

- Crew types assigned to each task reflect the required qualifications needed to perform the task and individual crew members are assumed to have all the qualifications associated with their crew type.

These modest assumptions demonstrate the broad scope of CSEM. Although CSEM is not capable of addressing all aspects associated with crew size evaluation, this step of the validation shows that its scope exceeds initial requirements and gives it the flexibility to evaluate crew requirements accurately. If these assumptions hinder the use of CSEM, then enhancement can be considered.

Validation of the model scope shows that CSEM has the ability to address a broad range of issues affecting crew requirements. This step in the validation identified two key assumptions: crew qualifications must be identified by crew type and excessive fatigue must be identified by workhour violations or the simple fatigue model. If an analysis can meet these assumptions, then it falls within the scope of CSEM. Because accepting these assumptions is reasonable for many analyses, this step of the validation shows that the scope of CSEM is sufficient to address many important issues.

4.1.2 Validation of the Conceptual Approach

This step in the validation examines how well the general approach for simulating crew member activities and calculating workhours matches reality. If the approach does not reflect the actual operating conditions, then predicted workhours and overall crew requirements will be incorrect. Comparing the approach used in CSEM to the factors governing shipboard activity answers the question: Does the conceptual approach of matching crew members to tasks accurately reflect actual shipboard activities?

Figures 4 shows the core of CSEM's conceptual approach and Appendix B contains a detailed description. Interviews and shipboard observations provide the data to validate the conceptual approach shown in Figure 4. Step 1, "Identify the timing of voyage segments," points to the effect of port calls and restricted waters passage on crew member activities. This step determines what tasks occur and when crew members are on duty; for example, cargo operations only occur when in port, and work schedules may change when the ship is in port. Interviews and observations validated the important influence of these events on activities. Shipboard observations identified a minor mismatch between the conceptual approach and shipboard operations. According to Figure 4, the timing of port calls, as specified in the voyage profile, is independent of the shipboard tasks. This assumption holds for the vast majority of activities; however, cargo operations can influence the sailing times of the ship. Recognizing this characteristic of CSEM, the voyage profile must be developed so that it is consistent with the time required to complete cargo operations (i.e., the duration of the port call in the voyage profile must be long enough to allow cargo transfer to complete). Otherwise, the workhour demand of cargo operations may be underestimated.

Not surprisingly, Step 2, "Determine when crew members are on duty," proved to be an important determinant of the tasks a person might perform and the hours crew members might work. In CSEM, crew members are "on duty" during regularly scheduled work periods, such as the watchstanding periods. Crew members might work even if they are not "on duty." They can be called upon to work at any time, depending on the priority of the task. This matches information gathered during interviews. Crew members stated that they might work when they are not "on duty," such as during port calls. This pattern of activity is consistent with the conceptual approach used in CSEM.

Steps 3 and 4 reflect the process used to determine the time tasks are to be performed. The conceptual approach assumes that shipboard tasks occur periodically, with the time they are next performed depending on the time they were last performed. For some tasks, such as watchstanding, the repetition is

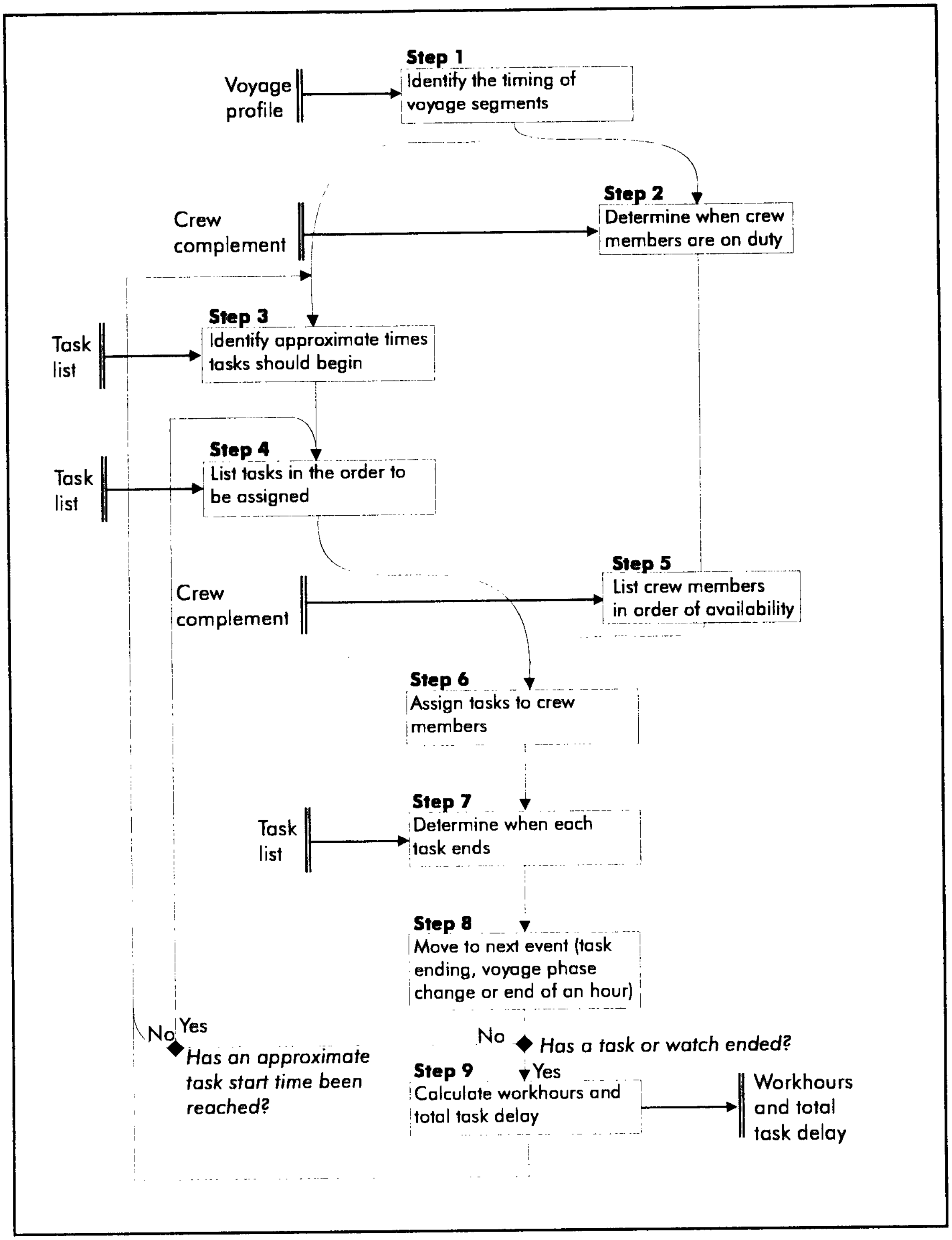

Figure 4. The key steps in CSEM's conceptual approach to simulating shipboard activities.

perfectly regular; every 4 hours the watch changes. Maintenance tasks may not be so regular, but the underlying process is similar. In fact, a planned maintenance program on many ships specifies the frequency with which certain tasks are performed. This matches the approach in Figure 4. This approach to simulating shipboard operations leads to a "to do" list of tasks that need to be performed. Comments from several mariners validated this approach, describing a string of maintenance tasks that accumulate on their "to do" lists. Frequently, the lower priority scheduled maintenance tasks are delayed when unexpected, high priority repair work supersedes the scheduled tasks. Conversely, during slow periods scheduled maintenance tasks may be completed in advance of their due date. Who performs these tasks and whether they will be delayed depends on a relatively complex relationship between task priority and the availability of crew members.

Step 6, "Assign tasks to crew members," addresses the approach used to determine which crew members perform the task or whether the task will be delayed. Figure 5 shows the detailed logic of how tasks are assigned and how disruptions to crew schedules are simulated. The top of Figure 5 shows a decision tree that defines the availability of crew members. The matrix at the bottom of the figure shows how task priority interacts with crew availability to determine whether a task is delayed, assigned, or interrupted so that work can begin on a higher priority task. This figure also shows the conditions under which a work period might be extended or sleep might be interrupted.

The primary issue affecting the validity of the conceptual approach is whether the factors that disrupt the simulated crew members' schedules in CSEM match the factors that disrupt actual crew members' schedules. For example, port calls will disrupt maintenance activities and sleep. CSEM should also

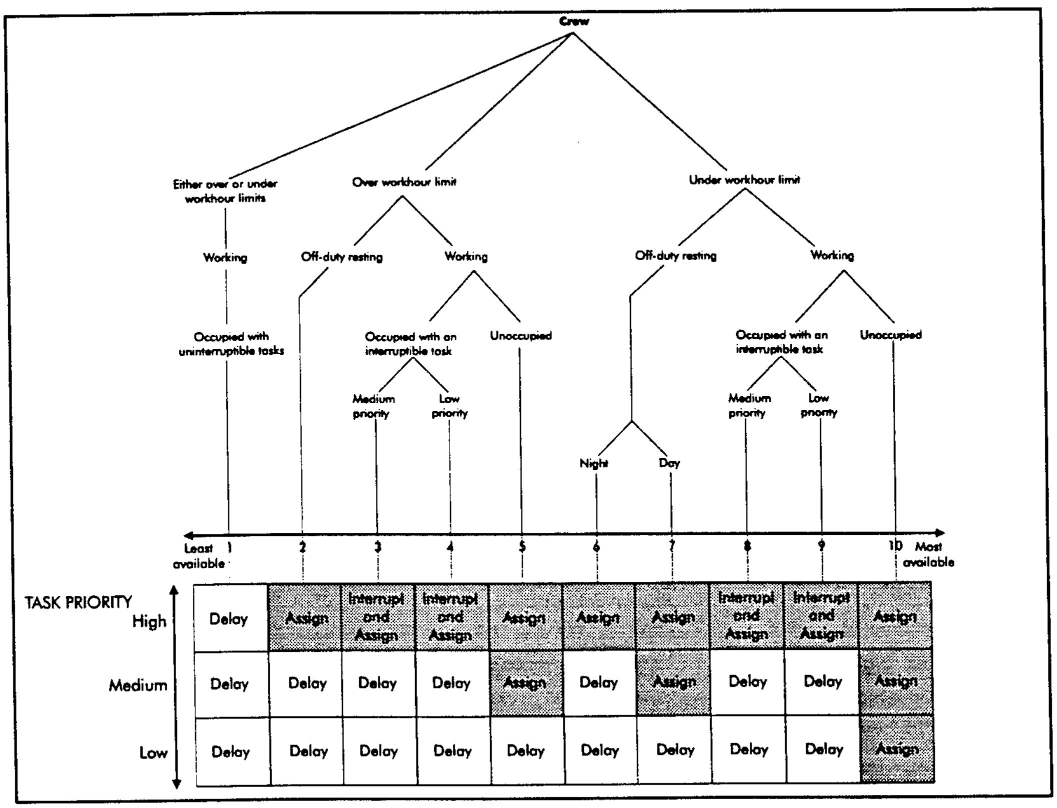

Figure 5. Task priorities and crew availability showing how the conceptual model assigns tasks and disrupts work schedules.

include the factors that lead to tasks being interrupted. CSEM must reflect these disruptions to produce a valid evaluation of crew requirements.

Shipboard interviews addressed the factors that disrupt work schedules. Table 3 shows the factors disrupting various activities. The numbers represent how often each factor was mentioned. To highlight those factors that were most frequently mentioned, the table includes only those cases that were mentioned more than four times. Appendix D describes how these factors vary across crew position (deck versus engine) and ship type (tanker versus freighter). The first column in Table 3 shows the importance of the watch schedule. Only a change in watch schedule and going ashore when in port would cause a crew member not to work the scheduled watch. A number of activities might cause a watch to be extended,

Table 3. Reported frequency of factors disrupting work schedules.

Factors	Not Work Watch	Extend Watch	Not Work Overtime	Extend Overtime	Awoken Unexpectedly	Change Sleep Times
Arrival/Departure		8			7	51
Mechanical/Electrical problems		10		11	20	
Emergency					17	
Cargo-related activities					5	7
Taking on stores/Provisioning*						
Steward dept./Clean up		5				
Drills						6
Administrative tasks/ Paperwork		8				
Crew grievances*						
Finishing tasks so that others may being working		9		5		
Overtime schedule/Budget varies			7			
Weather					7	5
Noise*						
Vessel traffic					6	
Change in watch schedule	8					
Going ashore	7					
Recovery from previous day's work/Rest for upcoming work			6			
Illness/Fatigue/Nap/Insomnia/ General health			6			
Sunday/Weekends/Prefer not to work			6			
Other		6				

*These factors were reported as not disrupting work schedules.

including arrival and departure, mechanical/electrical problems, and finishing tasks in preparation for others. This is consistent with Figure 5, where medium and high-priority tasks cause crew members to work beyond the normally scheduled watch periods. A similar pattern is shown for extending overtime, where high-priority mechanical/electrical problems and arrival/departure led crew members to extend their overtime periods. The decision not to work overtime depends on several factors not considered by CSEM. Overtime depends not only on maintenance requirements and port calls, but also on the company's budget and personal preference. This suggests CSEM may overestimate the hours worked by crew members on a ship that has more than the minimum number of crew members. In this situation, CSEM will have crew members perform optional tasks that might be deferred in reality. This difference will diminish as the crew is reduced to the minimum required. Table 3 also shows that crew members choose to rest in preparation for upcoming work rather than to work overtime. Figure 5 does not reflect this behavior. Table 3 shows that emergencies and mechanical/electrical problems are the most frequent reasons for crew members being awoken unexpectedly. This is consistent with Figure 5, which shows that only high-priority tasks interrupt a crew member's sleep. Comparing each case in Figure 5 to the outcomes specified in Table 3 validates the process used to assign tasks to crew members.

Validating the detailed task assignment process of the conceptual approach identified an important deficiency in CSEM. CSEM did not consider future events when simulating shipboard activities. Interviews showed that crew members plan for high workload periods by foregoing overtime tasks and resting. To address this issue, CSEM has been modified so that overtime and low priority tasks are delayed in anticipation of port calls or other high workload activities. CSEM now considers the future workhours associated with high-priority tasks when calculating crew availability.

An important assumption that underlies this approach is that shipboard tasks occur independently; whether a task occurs does not depend on whether another task has occurred. Shipboard interviews and observations suggest that this is a reasonable assumption. Tasks seem to occur periodically and whether or not they are delayed depends on crew member availability. Thus, the primary constraint on task occurrence is crew availability, as defined by workhour limits, time of day, and work schedule. If shipboard activities were considered in greater detail, this assumption might not hold. Considering tasks in greater detail would involve a set of subtasks for each of the current tasks. It is very likely that these subtasks would be interdependent. For the current level of detail, the observations and interviews suggest it is safe to assume that the timing of voyage segments, task priority, and crew availability are the primary factors that govern shipboard activity.

The validation of the conceptual approach shows that CSEM simulates activities and calculates workhours in a way that is consistent with the factors that govern shipboard tasks. This step in the validation process also identified a key improvement to CSEM that enhances its validity. Before the validation, CSEM simulated task occurrence and assigned tasks without regard for future workload. This was modified so that future high workload periods, such as port calls, are now considered before tasks are assigned. This modification provides a conceptual approach that is more consistent with shipboard activity. The validation of the conceptual approach suggests that CSEM can produce reliable estimates of crew requirements.

4.1.3 Validation of CSEM Implementation

This step in the validation process shows how well the computer implementation reflects the conceptual approach. The conceptual approach describes what CSEM should do to simulate shipboard activities and evaluate a proposed crew; however, mistakes may occur in translating the conceptual approach into the language of the computer. Validation of CSEM implementation examines the computer coding of the model to establish that its calculations are correct. Validating the CSEM implementation answers the question: Does the logic of the computer program accurately reflect the conceptual approach?

Two sets of tests validate the CSEM implementation. In the first set, individual software modules are examined to ensure that they function correctly. In the second set of tests, a series of relatively simple scenarios are examined. Simple scenarios are used because the behavior of a single crew member or the timing of a single task can be anticipated and evaluated more easily than the entire crew performing all their tasks. Testing individual software modules ensures that the individual elements of CSEM operate properly, while the test scenarios ensure that all the modules work together to generate accurate results.

Table 4. Simulation modules and corresponding validation criteria.

Simulation Module	Validation Criteria
Input data generation	Data from the CSEM interface must match the simulation requirements.
Track voyage progression	The sequence and timing of port calls and phase changes must match specified timeline.
Calculate interval between task occurrences	The calculated interval between tasks must reflect task data and task delays.
Update variables at end of task	Update variables at the beginning of task
Calculate crew availability	Changes in hours worked, time of day, and task involvement must be reflected in the level of availability.
Allocate crew to tasks	Assignment process must match Figure 5.
Allocate crew to tasks in the future	Future high priority tasks must be allocated to crew to identify future workload peaks.
Calculate future workhours	Future workhours must match the work demand of future high priority tasks.
Calculate crew members over workhour limits	Crew members who have exceeded workhour limits must be accurately identified so their availability to perform tasks can be adjusted.
Update hours worked	The hours worked must be updated to reflect time worked by crew members. This includes time spent performing tasks and idle time while on duty.
Update hours busy with tasks	The hours spent performing tasks must be updated to match the time spent working.
Remove crew from tasks	After a task ends, crew members must be released so they are able to work on other tasks.

Table 5. Simulation test scenarios and expected outcome.

Test Scenarios	Validation Criteria
Series of port calls with no people or tasks	Voyage profile
1 person, no tasks	Availability, Alertness, Workhours
1 person, low priority, interruptible task	Availability, Workhours, Time busy, Task timeline
1 person, 1 non-interruptible, medium priority task	Availability, Task timeline
1 person, 1 high-priority task	Availability, Task timeline
1 person, 1 watchstanding task	Availability, Alertness, Time busy, Workhours
1 person, 1 watch optional task and watchstanding	Availability, Time busy, Workhours, Task timeline
1 person, 2 tasks, one high-priority and one low-priority	Time busy, Task delays, Task interruptions
1 person, 2 tasks, one current, low-priority task and one high-priority task in the future	Availability, Task timeline
2 people, 1 task requiring one person	Availability, Time busy, Workhours, Task timeline
2 people, 1 watchstanding task	Availability, Time busy, Workhours, Task timeline
2 people, 2 independent tasks	Availability, Task timeline
2 people, 1 task requiring two people	Time busy, Task timeline
2 people, 1 task requiring two people in two crew pools	Time busy, Task timeline
2 people, 2 tasks, one high-priority and one low-priority	Time busy, Task delays, Task interruptions
1 person, all tasks that compose a complete day	Task timeline
1 person, performing all tasks during a phase change	Task timeline
Full crew, no tasks	Availability, Alertness, Workhours
Full crew, all tasks	Task timeline

Table 4 shows the modules tested and the validation criteria used for each test. The validation criteria for the individual modules reflected the expected input-output characteristics. A module that did exhibit the expected input-output characteristic was revised and the module was retested. Table 5 shows the test scenarios used to test the behavior of the modules before they were integrated into CSEM. Each test scenario generates a timeline of model behavior that can be easily validated against expectations. For example, the workhours for one person performing no tasks can be calculated by hand by simply adding the hours on duty. Similarly, the simplicity of the other scenarios makes it possible to anticipate the results. The series of test scenarios are also designed to progress from simple to complex; each scenario tests a successively more complex aspect of CSEM. The validation criteria for each test scenario are timelines of values or activities. For example, crew member availability is represented in CSEM by a variable that fluctuates from 5 to 100, depending on the status of the crew member. The timeline of crew availability should show availability increasing when the crew member goes on duty and declining when the crew member begins working on a task. Similarly, alertness should fluctuate according to the equations that predict alertness based on the time of day, the amount of sleep, and the time since last sleeping. Testing the individual simulation modules and running the test scenarios identifies inconsistencies in data coding, syntax errors in the programming, and logic errors.

The validation of CSEM implementation shows that the computer code accurately reflects the conceptual approach. This step in the validation identified and corrected several minor mistakes in the computer implementation. After these corrections were made, the tests of the individual modules and the wide variety of test scenarios showed that the computer implementation of CSEM is consistent with the conceptual approach.

4.1.4 Validation of the CSEM Input

This step in the validation process assembles representative task data for input to CSEM. The input to CSEM includes the list of shipboard tasks and the data that describe how often each shipboard task occurs, how long it lasts, who performs the task, and its relative priority. Because these data determine the frequency and duration of simulated activities, the validity of CSEM's predictions depend on their accuracy. This step in the validation process answers the question: Do the input data accurately reflect shipboard activities?

Representatives from the shipping industry reviewed the task list before shipboard data collection. Industry representatives suggested many revisions and additions to the task list. In addition, the task list was reviewed to ensure its consistency with the requirements of estimating crew requirements. These revisions were combined, reconciled, and implemented to produce the task list in Appendix A. The final task list describes shipboard activities with 154 tasks.

The validated task list provides the basis for shipboard data collection. One of the two shipboard interviews focused on collecting detailed information about each task. During the interviews, mariners were shown the task list and were asked about every task they performed. They were also asked to add any tasks that were missing from the list. Mariners considered the task list to be complete, and they made very few additions. Appendix C includes the complete data collection protocol that guided the discussions with the mariners. The specific data collected for each task includes:

- The minimum, maximum, and average task duration.
- The minimum, maximum, and average frequency of occurrence.
- Whether the task is a required or optional part of watchstanding, or if it cannot be performed while on watch.
- The number and types of crew members required to perform the task.
- Whether the task could be passed to another crew member.
- Whether the task could be interrupted and completed later.

The shipboard data collection generated data for over 3,000 task instances. All the tasks had more than one person estimate the data. Previous research has shown that people can accurately estimate time allocations between tasks (Carroll & Taylor, 1969), but that estimates can depend on factors such as workload levels (Hicks, Miller, & Gales, 1977). Collecting data from multiple mariners generates more precise estimates. In most cases these estimates did not match exactly, so some reconciliation was required. Two processes ensure a comprehensive reconciliation of the data. The first process examines the distribution of the individual data elements, such as task duration. These distributions identify inconsistencies that are resolved by examining the differences between ships and crew members. These differences were used to select representative values for each task and identify the need to generate alternate data sets. The second process examines the tasks assigned to each crew type. Analysis of the tasks performed by each crew type complements the analysis of the individual tasks by identifying how they fit into the workday of the crew members. This reconciliation process generated two separate sets of task data, one for a tanker and one for a freighter. The two task lists reflected differences between the ships. Not surprisingly, the tankers and freighters required different sets of task data.

The validation of the CSEM input data shows that the task list accurately reflects shipboard activities and that detailed task data have been successfully collected. This step in the validation identified the need for two sets of input data to reflect the differences between ships. These differences reflect different cargo handling for the two types of ships. Validating the task list shows that it comprehensively describes all the shipboard activities. Validation of the task data shows that two sets of task data can cover a wide variety of operating conditions.

4.1.5 Validation of CSEM Output

This step of the validation compares the output of CSEM to actual shipboard data. Examining the output of CSEM provides the most direct and important measure of its validity. If CSEM does not predict average workhours and overall crew requirements accurately, then its output is not valid. Validation of CSEM output answers the question: Does the output of the model accurately mimic crew activities, workhour averages, and evaluate crew requirements?

Validation of CSEM output compares the model's output to actual shipboard data at each of four levels of detail (Appendix C contains the complete data collection forms). A very detailed comparison shows that CSEM replicates the actual activities onboard the ship, while a broader analysis shows that the crew predicted by the model corresponds to the crew used onboard actual ships. Comparing the output at different levels of detail provides a more comprehensive validation than one that focuses on any specific output of CSEM.

The four levels of detail include:

- Overall crew requirements.

- Average hours worked/day and number of workhour violations.

- Timeline of work and rest.

- Timing and sequence of tasks.

Differences in manning levels exist for a wide variety of reasons, including:

- Difference in trade and route.

- Variation in shipboard technology.

- Vessel age, level of technology, and maintenance.

- Variation in operating procedures.

- Shore help for loading container ships.

- Availability of a loading mate.

- Involvement of mates in deck maintenance.

Some specific differences between ships in this study include the type of cargo, type of power plant (steam versus gas turbine), age, trade route, and size. Table 6 summarizes the characteristics of each ship.

Table 6. Characteristics of the ships included in task data collection phase of this study.

Ship No.	Type	Year Built	Length (feet)	Weight (gross tons)	Power Plant	Trade Route	Cargo Capacity
1	Freighter	1970	720	23,785	Steam	West Coast - Hawaii	1451 containers, 10,000 light tons molasses tank capacity
2	Tanker	1959	645	17,822	Steam	East Coast - U.S.	210,241 bbls
3	Tanker	1976	650	22,735	Gas Turbine	West Coast - U.S.	265,000 bbls
4	Freighter	1972	780	38,656	Steam	West Coast - U.S.	2,305 containers
5	Tanker	1972	810	70,000	Steam	West Coast - Alaska - Hawaii	499,728 bbls

Table 7 shows that the overall crew requirements identified by CSEM correspond closely to those seen on actual ships. The CSEM analysis of the freighter and tanker considered a typical voyage of 10 days. This voyage included a port call at the beginning and one at the end. The restricted waters transit for the first port call lasted 4.5 hours and the restricted waters passage for the second port call lasted 1.5 hours. Cargo was loaded at the first port and discharged at the second, during the 32 hours spent in each port. These parameters are typical of the vessels shown in Table 7 and common to many other freighters and tankers. Selecting representative parameters should produce representative estimates of crew requirements.

Although general agreement at this level is encouraging, a complete validation requires a more detailed analysis of how CSEM simulates shipboard activities.

Table 7. Crew for each of the six vessels involved in the study and those for the CSEM evaluation.

Crew Position	Ship Number						
	1-Freighter	4-Freighter	CSEM Freighter	2-Tanker	3-Tanker	5-Tanker	CSEM Tanker
Master	1	1	1	1	1	1	1
Chief Mate	1	1	1	1	1	1	1
2nd Mate	1	1	1	1	1	1	1
3rd Mate	1	1	1	1	2	1	1
Chief Engineer	1	1	1	1	1	1	1
1st Assistant Engineer	1	1	1	1	1	1	1
2nd Assistant Engineer	1	1	1	1	1	1	1
3rd Assistant Engineer	2	2	2	1	2	1	1
Chief Electrician	1	1[1]	1	0	0	0	0
Radio Officer	1	1	0	1	0	1	0
Boatswain	1	1	1	1	1[2]	1[2]	1
Pumpman	0	0	0	2[7]	0	2	2
Reefer	1[3]	0	1	0	0	0	0
Wiper/Oiler	1	1	1	0	0	0	0
Able-bodied Seaman	7[4]	6	6	6	5	5	6
QMED	3	3	3	3	0	0	3
Utility	0	0	2	2[8]	2	1	1
Chief Steward, Steward	1	1	1	1	1	1	1
Chief Cook, Cook, Asst. Cook	2[5]	2	2	0	0	1	2
Messman, Room Steward	1	3	0	0	1	2	0
TOTAL[6]	**28**	**28**	**27**	**24**	**20**	**22**	**24**

[1] Also reefer
[2] 8 - 12 watchstander
[3] Also electrician
[4] One is daywork / maintenance
[5] Assistant cook, also utility
[6] The cadets were not included in the totals.
[7] Chief pumpman and 2nd pumpman
[8] One helped cook and clean mess and the other did stateroom cleaning and kitchen work

A question during the shipboard data collection addressed the need for additional crew members. Almost all the mariners could identify an additional crew member that is needed. The most frequently cited additions include an able-bodied (AB) seaman, a third mate, a general vessel assistant, a first assistant engineer, a cook, and a utility. The need for an additional third mate emerged as the most broadly requested addition to the crew, followed closely by the need for an AB seaman, and first assistant engineer. Approximately 33 percent of the mariners interviewed suggested that either an AB or third mate be added to the crew. Crew members from all departments, including the engineering and steward departments, all recognized the need for an additional third mate to relieve the chief mate from watchstanding duties. This need was also expressed as a need for a loading mate, who would assume the cargo handling responsibilities while in port. CSEM's predictions of crew member workhours is consistent with these interview results, validating the output of CSEM.

A more detailed view of CSEM output considers the hours worked and slept. This analysis compares the predictions of CSEM to the data collected during the interviews and during a previous Coast Guard sponsored study (Sanquist, et al., 1996). The interviews asked mariners to identify the hours worked and slept in two ways. At the beginning of the interview, they were asked to complete a timeline of a typical day, showing when they sleep, work, eat, and relax. These estimates are referred to as timeline estimates of work and sleep. At the end of the interview they were asked to estimate their average amount of sleep and work each day. These are termed direct estimates of work and sleep. The other Coast Guard study asked mariners to keep a logbook and record the time they went to sleep, the time they awoke, and the time they began and stopped working. These estimates are termed logbook estimates. CSEM can be validated by comparing its output to each of these estimates.

The overall average number of workhours per day predicted by CSEM for the tanker and freighter is 11.49. The overall average from the logbook data is 11.45 with a confidence interval of $\pm$0.41.[9] Because the average workhours predicted by CSEM falls within the confidence interval, the workhour average produced by CSEM is not statistically different from the average workhours observed on actual ships. The direct estimate and timeline show similar results, with an average of 10.46 $\pm$ 0.56 for the timeline and 10.68 $\pm$ 0.68 for the direct estimate. Because the interview data, particularly the timeline estimates, reflect the typical day, the interview data most likely underestimate actual workhours. For this reason, the logbook data offer a better point of comparison for CSEM. The nearly exact match between workhours confirms the accuracy of CSEM.

To be useful, CSEM must also predict workhour variations between ship types and watch type. Table 8 shows how well the various estimates of work and sleep agree with each other and with CSEM. The estimates of work are all highly correlated. The "timeline" and the "direct estimate" are almost perfectly

[9] Based on a 95 percent confidence interval.

correlated, which is not surprising because the data were collected from the same group of people. The "logbook" data are less highly correlated, showing some discrepancies with the interview data. A potential source of this discrepancy is that the interview data forced mariners to consider a typical day in open waters and an average number of hours. The logbook data reflect actual sleep and work times for mariners on voyages similar to the one examined by CSEM over 10 to 30 days. The logbook data are more likely to reflect the extra work hours associated with port calls and other events that might disrupt the schedule of a typical day.

The model predictions of CSEM for workhours are highly correlated with the logbook and interview data, showing that the model can accurately reflect the workload differences between ship types and watch types. The correlation of the model with the logbook data is the same as the correlation of the interview data with the logbook data, suggesting that CSEM can estimate workhours as well as interviews with mariners. All correlations were calculated using the average hours of work and sleep for each crew type for each ship type.

Because the correlations are based on samples with imperfect reliability, the true correlation is higher than that shown in Table 9. The reliability of CSEM's workhour predictions is 0.98[10] and the reliability of the logbook data is 0.69.[11] CSEM's reliability is high because all operational variability, except task duration, is held constant. The operational variability in the logbook data limits its correlation with CSEM. Adjusting the correlation for the reliability of the logbook data and CSEM's predictions improves the correlation of CSEM to 0.82.[12] This high correlation shows that CSEM accurately reflects workhour differences between ship and watch types.

Table 8. Correlations between actual work and sleep and CSEM predictions.

	Work				Sleep			
	Timeline	Direct Estimate	Logbook	CSEM	Timeline	Direct Estimate	Logbook	CSEM
Timeline	1	0.95	0.69	0.76	1	0.22	-0.14	0.30
Direct Estimate	0.95[13]	1	0.69	0.76	0.22[16]	1	0.50	0.25
Logbook	0.69[14]	0.69[14]	1	0.68	-0.14[16]	0.50[15]	1	-0.02
CSEM	0.78[13]	0.76[13]	0.63[14]	1	0.30[16]	0.25[16]	-0.02[16]	1

[10] Based on the average intercorrelation of five model runs, computed using the Fischer transform.
[11] Based on the standard error of the mean for each watch type and the squared deviation of these means.
[12] Corrected for attenuation correlation coefficient.
[13] $p < 0.01$ (two-tailed) df = 10.
[14] $p < 0.05$ (two-tailed) df = 10.
[15] $p < 0.1$ (two-tailed) df = 10.
[16] $p > 0.1$ (two-tailed) df = 10.

The estimates of sleep are not as consistent as the work estimates. The timeline estimate and the direct estimate are only slightly correlated and the timeline estimate is negatively correlated with the logbook data. The direct estimate agrees moderately well with the logbook data; however, the agreement is not as strong as the work estimates. The output of CSEM shows a modest correlation with the interview data, but does not correlate with the logbook data. This is not surprising because the focus of CSEM has been on estimating workhours and not sleep. The algorithms used to predict sleep are very simple. CSEM assumes that mariners are sleeping if they are not working, eating, or preparing to work.

Several factors might explain the poor correlation between the estimates of sleep. Table 9 shows the detailed data used to calculate the correlations. These data show that the timeline data consistently overestimate sleep, particularly for the stewards department and the 4 - 8 watchstanders. The timeline may overestimate sleep in three ways. First, other activities may be included in the time periods identified as sleep time. For example, the interval between when the mariners awaken and the when they go to breakfast is coded as sleep in the timeline. Second, the timeline shows the time mariners went to bed and not the time they actually went to sleep. The logbooks identify the actual time spent sleeping and record sleep latency separately. In contrast, the timeline estimates combine the sleep latency with the time spent sleeping. Third, the logbook data record actual sleep as it is affected by port calls, weather, and other disruptions. The timeline data represent a typical day, which is probably a best case estimate that would be higher than most actual sleep periods. The detailed data in Table 9 confirm these assertions, showing that the timeline data consistently overestimate time spent sleeping as compared to logbook data. The CSEM output shows that the model consistently overestimates time spent sleeping, suggesting that CSEM needs to include other factors to predict sleep accurately.

Table 9. Number of hours slept per day.

	Tanker				Freighter			
Watch Type	Direct Estimate	Timeline	Logbook	CSEM	Direct Estimate	Timeline	Logbook	CSEM
0 - 4	6.7	7.7	6.7	7.7	6.9	7.6	6.9	7.4
4 - 8	7.4	7.6	6.5	8.2	6.2	7.7	5.2	7.7
8 - 12	7.4	7.5	6.6	7.1	6.6	7.0	7.8	6.8
Command	7.3	7.4	7.2	8.7	6.6	7.0	7.8	8.9
Operational	7.2	7.5	6.8	8.8	7.3	7.7	7.0	8.8
Steward	6.6	7.3	5.8	8.1	6.8	7.5	6.2	8.2

Table 10 reflects the relatively high correlations between the estimates of workhours and CSEM predictions, showing that the model predicts the workhours for all watch types for the two ship types. CSEM tends to overestimate the workhours of the stewards on the freighters. But in general, CSEM shows high agreement with shipboard operations.

Table 10. Number of hours worked per day.

Watch Type	Tanker				Freighter			
	Direct Estimate	Timeline	Logbook	CSEM	Direct Estimate	Timeline	Logbook	CSEM
0 - 4	11.6	11.7	11.4	12.0	10.4	10.9	11.5	11.8
4 - 8	11.1	10.6	11.7	11.9	11.0	10.6	12.4	11.8
8 - 12	11.3	11.4	11.9	11.9	10.5	10.4	10.9	11.3
Command	8.6	8.1	10.7	10.5	8.3	8.3	10.6	11.1
Operational	10.3	10.0	11.6	10.5	9.4	8.6	9.5	10.1
Steward	12.0	11.6	12.7	12.9	11.1	10.9	10.8	12.8

The pattern of workhours that CSEM generates for each crew member also suggests that the model accurately simulates shipboard activities. A factor analysis identified five unique work/rest patterns that correspond to each of the watch types, with the command and operational crew members belonging to the same group.[17] This result shows that timing of work periods for each of the six watch types predicted by CSEM corresponds to the different watch types. This, in turn, demonstrates that CSEM captures the constraints that affect when and for how long mariners work.

Analysis of when the tasks are performed shows that the model behaves as expected. Table 11 summarizes the data describing tasks that were delayed and those that were not performed. The average task delay in Table 11 is shown only for those tasks that were delayed. Tasks were labeled "not performed" if they were

Table 11. The effect of task priority on task delay and task performance.

Ship Type	Priority	Average task occurrences per day	Average % of tasks delayed per day	Average delay in minutes	Average % of tasks not performed per day
Tanker	High	83.0	9.6	135.0	0.3
	Medium	38.7	23.4	573.0	2.4
	Low	6.1	46.8	1644.1	18.4
	All	127.8	15.6[18]	453.8[18]	4.0[18]
Freighter	High	84.8	10.0	67.8	0.3
	Medium	37.4	20.8	612.2	1.8
	Low	5.6	46.1	1845.7	18.6
	All	127.8	14.4[18]	483.0[18]	4.0[18]

[17] A principal components analysis, using eigenvalues greater than one as the criterion for inclusion, identified five factors. A varimax rotation produced a factor matrix that shows a loading for each crew member of at least 0.75 on one of the five factors.

[18] Averages are the weighted arithmetic mean of the high, medium, and low priority categories. The overall means are weighted by the number of task occurrences in each category and represent the means of the overall population.

delayed past a change in the voyage phase (i.e., when the ship passes from in port to restricted water). High priority tasks are rarely delayed or not performed and low priority tasks are delayed more often, and for a longer period, than medium priority tasks. Table 11 also shows no differences between the two ship types.

The five different approaches to model validity provide a comprehensive examination of CSEM's ability to evaluate crew requirements. Each validation approach (CSEM scope, conceptual approach, CSEM implementation, input data, model output) provides complementary evidence regarding the ability of the model to accurately simulate crew requirements. The converging evidence of each approach suggests that CSEM can accurately estimate workhours and overall crew requirements.

4.2 Model Sensitivity, Range of Applications, and Potential Simplifications

The sensitivity analysis addresses three general issues. First, it shows how the CSEM predictions depend on the accuracy of input data, such as estimated task durations. This indicates if any shipboard tasks deserve particular attention to ensure accurate estimates of their parameters. Second, the sensitivity analysis examines the relative importance of internal model parameters, such as the influence of alertness on estimated sleep. Third, the results identify how the model might be simplified. The sensitivity analysis addresses each of these issues as a guide for future analysis of critical issues.

4.2.1 Analysis of Input Data Uncertainty

This analysis considers the effect of errors in task data used as input to CSEM. Because the number of hours worked depends on task data, such as duration and frequency of occurrence, errors in these data are likely to affect workhour estimates and estimated crew requirements. This analysis examines whether CSEM is sensitive to errors in estimating task data for a small subset of the complete task list. In particular, tasks with a high workhour demand (tasks that occur frequently, have a long duration, or require a large number of people) may influence the output more than tasks with a low workhour demand. Multiplying the duration by the frequency of occurrence by the number of persons required generates the workhour demand of each task. If errors in estimating the duration of high workhour tasks have a large influence on CSEM output, then quantifying the effects of these errors can guide additional data collection by focusing on the tasks that have the largest effect on crew size evaluations. This sensitivity analysis considers effects of overestimates of task duration and identifies when more precise data are required to evaluate crew requirements accurately.

The sensitivity analysis considers three levels of uncertainty for a set of five high workhour tasks and five low workhour tasks. One of these high workhour tasks is cargo loading and another is cargo discharge. These tasks, combined with three other high workload tasks, demand an average of 18.1 workhours per day. This accounts for 6.4 percent of the average of 283 workhours per day generated by all the other tasks. However, the contribution of these tasks is much less in open waters when cargo loading or unloading is not a factor and greater in port. The five low workhour tasks demand an average of 0.31 person-hours of work each day, and account for a smaller percentage of the total workload—1.55 hours per day, or 0.55 percent of the total workhours. Appendix D identifies the high and low workhour tasks.

Six task data sets were created by increasing the task duration of the five high and low workhour tasks by 20, 50, and 100 percent to reflect the effect of erroneous estimates. Each of these data sets was used as input to CSEM. Table 12 shows the output of CSEM using the six data sets.

Table 12. Average workhours with workhour limit violations in parentheses for three levels of data uncertainty.

		High workhour burden tasks			Low workhour burden tasks		
Watch Types	**Baseline**	**+20%**	**+50%**	**+100%**	**+20%**	**+50%**	**+100%**
12 - 4	12.0 (3.8)	12.3 (5.3)	12.4 (4.7)	12.2 (5.3)	12.3 (4.2)	12.2 (4.2)	12.1 (4.7)
4 - 8	11.9 (6.5)	12.1 (7.2)	12.4 (7.8)	12.6 (7.4)	12.1 (6.2)	12.2 (6.6)	12.3 (6.8)
8 - 12	11.9 (4.9)	12.0 (5.7)	12.4 (7.0)	12.7 (9.5)	12.2 (5.6)	12.1 (5.5)	12.3 (6.7)
Command	10.5 (0.5)	10.8 (0.9)	10.7 (1.6)	10.5 (1.4)	10.9 (0.8)	10.7 (1.0)	10.4 (0.9)
Operational	10.5 (1.7)	10.3 (1.0)	10.3 (1.9)	10.2 (1.7)	10.7 (0.5)	10.1 (1.2)	10.0 (0.6)
Steward	12.9 (11.4)	12.6 (11.5)	12.5 (9.6)	12.4 (10.0)	12.6 (8.5)	12.5 (10.0)	12.5 (10.3)
Overall	11.8 (4.9)	11.7 (3.4)	12.0 (4.5)	12.0 (5.1)	12.0 (3.2)	11.8 (4.3)	11.9 (4.5)

Data uncertainty for the two sets of five tasks does not change the output of CSEM dramatically. This analysis also shows that even errors in several high workhour tasks do not influence the workhour estimates of CSEM output. These results suggest that CSEM produces a robust analysis of crew requirements that is not highly dependent on the uncertainty of a particular task duration.[19] However, uncertainty for high workhour tasks does affect the average number of violations;[20] the greater the error, the greater the number of violations. Table 12 shows that this effect is concentrated on the 8 – 12 watch type, which may reflect the demands of cargo operations on the Chief Mate. The results suggest that workhour violations are more sensitive to data uncertainty compared to average workhours. Because data uncertainty affects the predicted workhour violations and the conclusions that can be drawn from a CSEM analysis, it is important to understand when data uncertainty can influence results.

Table 13 summarizes the task delay information. Like the workhour comparison in Table 12, data uncertainty for the two sets of five tasks does not affect the output of CSEM dramatically. The average number of tasks delayed and the average number of tasks not performed does not show an effect of uncertainty.[21] The average delay does show an effect, but only for the high workhour demand tasks and the

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[19] Average workhours, two factor repeated measures ANOVA; $p > 0.1$, $F(6,28) = 0.77$

[20] Violations, two factor repeated measures ANOVA; $p < 0.01$, $F(6,28) = 3.49$

[21] Number of tasks delayed, two factor ANOVA; $p > 0.1$, $F(6,104) = 8.63$; number of task not performed, two

low workhour demand tasks with the 100 percent estimation error.[22] These results show that CSEM is relatively robust to errors in task duration estimate, although the effect of estimation errors for high workhour demand task can be detected.

Table 13. Task delay information for three levels of data uncertainty.

Condition	Average percent of tasks delayed	Average delay in minutes	Average percent of tasks not performed
High Workhour			
+ 20%	15.6	581.2	3.8
+50%	16.0	617.0	4.0
+100%	14.8	659.1	4.4
Low Workhour			
+20%	15.3	534.5	4.0
+50%	15.7	470.7	3.9
+100%	14.9	554.2	3.9
Baseline	15.6	453.8	4.0

4.2.2 Analysis of Internal Model Parameters and Algorithms Affecting Sleep Estimates

The validation of CSEM showed a poor correspondence between the average sleep predicted by CSEM and the logbook data. CSEM overestimated sleep of all watch types, and variations between watch types and ship types did not correspond to those observed on actual ships. This suggests the algorithm CSEM used to predict sleep needs to be modified. CSEM predicts sleep using a very simple algorithm: if the mariners are working, eating, or preparing to work, they are not sleeping; otherwise they sleep. One obvious factor that may govern when mariners sleep is their level of alertness. An off-duty mariner who is not tired may not go to sleep, but may read, exercise, or watch a video instead. CSEM may be able to predict time spent sleeping more accurately if it uses an estimate of mariner alertness to estimate sleep periods.

The simple algorithm used to predict sleep can be augmented so that CSEM predicts mariners will sleep only when they are not working, eating, preparing for work, and if their alertness is below a certain threshold. Making the predicted sleep dependent on an alertness threshold is more realistic because CSEM will predict mariners will sleep only when they are tired. Alertness was predicted using a model developed by Akerstedt and Folkard (1995). The model calculates alertness using the length of the last sleep period, the number of hours awake, and the circadian rhythm. A sensitivity analysis was used to understand how the alertness threshold affects the estimates of sleep. This analysis also shows which alertness threshold enables CSEM to best emulate logbook data. Using this threshold, CSEM produces very good estimates of

factor ANOVA; $p > 0.01$, $F(6,104) = 0.37$.

[22] Average delay, two factor ANOVA; $p < 0.001$, $F(6,104) = 5.51$.

mariners' sleep.

Table 14 shows the results of the sensitivity analysis, indicating that the alertness threshold has a major effect on the amount of sleep the model predicts. An alertness threshold of 11.5 enables CSEM to predict the average sleep of mariners almost exactly (6.58 hrs/day) compared to logbook data, which show mariners sleep 6.61 hrs/day. This table also shows how well CSEM reflects the differences

Table 14. Average hours slept for different alertness thresholds.

Alertness Threshold	Overall	0 - 4 watch	4 - 8 watch	8 - 12 watch	Command	Daywork	Steward
Tanker 10	5.0	4.5	4.9	4.8	5.5	5.7	5.1
Tanker 11	6.0	5.4	5.7	5.8	6.6	6.5	6.3
Tanker 11.5	6.6	6.1	6.0	6.1	7.3	7.2	6.8
Freighter 11.5	6.9	7.5	6.5	6.5	6.4	7.6	7.0
Tanker 12	7.0	6.5	6.3	6.4	8.2	8.1	7.5
Baseline (No Threshold)	8.1	7.7	8.2	7.1	8.7	8.8	8.1
Logbook	6.6	6.7	6.5	6.6	7.2	6.8	5.8

between ship and watch type. The revised algorithm that includes the alertness threshold provides a much better estimate of sleep patterns, but the correlation is still relatively weak. However, even this weak correlation provides a better estimate of sleep patterns than those obtained by asking mariners to fill out a timeline of work and sleep. A possible reason for the poor correlation is the relatively crude model of alertness used to determine when mariners are likely to begin sleeping. The model of alertness included in CSEM makes several simplifying assumptions that may undermine the alertness and consequently the sleep predictions. The alertness model assumes a continuous sleep episode and may not generalize to split sleep periods seen on ships. The model also does not consider the effects of sleep inertia or work inertia noted in Sanquist et al. (1996). These limits are confirmed by the weak correlation (0.18) between alertness predicted by CSEM and the logbook data.

4.2.3 Analysis of Potential Simplifications

This analysis examines whether CSEM can be simplified without jeopardizing its validity. In particular, this analysis considers whether a less complex task list can be used for CSEM analyses. The current, detailed task list (Appendix A) contains 154 tasks that describe shipboard activities in considerable detail; however, the detailed task list complicates data collection, data entry, and the use of CSEM. If a simplified version of this task list does not undermine the accuracy of its predictions, then it would make CSEM easier to use. This analysis answers the question: How does a simplified task list influence the predictions of CSEM?

The task list is currently organized into 15 categories, with 3 to 33 tasks in each category. The objective of simplifying the task list is to combine tasks to produce a more manageable description of shipboard activity. Because the task durations and crew requirements vary dramatically within each category, it is not possible to combine all the tasks within each category. Even with this constraint, it is still possible to reduce the task list considerably. To simplify the task list, individual tasks within a category were combined when similar crew types were needed to perform them. Also, tasks were combined only if they occur during the same voyage phases (port, restricted waters, open waters). For example, many engineering maintenance tasks require similar crew types and so they can be combined. Cargo handling and deck maintenance tasks cannot be combined because some occur in port and some occur at sea; they also draw upon different crew types. The simplified task list contains 83 tasks compared to the original 154 tasks. Appendix A shows the detailed and simplified task lists, together with the task definitions.

Table 15. Average workhours and the number of violations (in parentheses) for the simplified task list.

Watch Type	Detailed Task List	Simplified Task List	Logbook Data
0 - 4	12.0 (3.8)	12.4 (5.7)	11.4
4 - 8	11.9 (6.5)	12.0 (6.9)	11.7
8 - 12	11.9 (4.9)	12.2 (6.0)	11.9
Command	10.6 (0.5)	11.5 (4.8)	10.7
Operational	10.5 (1.7)	10.1 (1.8)	11.6
Steward	12.9 (11.4)	12.5 (9.9)	12.7
Overall	11.8 (4.9)	11.9 (4.4)	11.7

Table 15 shows how the average workhours and number of violations predicted by the model change when a simplified task list is used. The logbook data are also shown in this table to show how the results with the simplified task list compare to actual operating conditions. Simplifying the task list does not change the average workhours and number of violations dramatically.[23] Table 15 shows that average workhours and workhour violations change only slightly. Table 16 shows the correlation (based on the average workhours in Table 15) between CSEM predictions using the detailed and simplified task lists and workhours from the logbooks. This table shows that reducing the task list undermines the ability of CSEM to predict workhours. The agreement between CSEM's workhour predictions and the logbook data drops from 0.78 for the detailed task list to 0.36 for the simplified task list.

Using the simplified task list produces less accurate estimates of workhours as measured by the correlation between the predicted workhours and the logbook data. In addition, the simplified task list may limit the

[23] Violations, two factor repeated measures ANOVA; $p > 0.05$, $F(1,8) = 4.97$; Workhours, two factor repeated measures ANOVA; $p > 0.10$, $F(1,8) = 3.28$.

Table 16. The correlation between CSEM predictions using the detailed and the simplified task list and the logbook data.

	CSEM Detailed Task List	CSEM Simplified Task List	Logbook Data
CSEM Detailed Task List	1	0.85	0.78
CSEM Simplified Task List	0.85	1	0.36
Logbook Data	0.78	0.36	1

ability of CSEM to examine important issues. Combining the original tasks into a simplified task list assumes that factors affecting task parameters, such as duration or crew requirements, will affect all of the original tasks equally. When this is not true, the simplified task list may not represent shipboard activities accurately. For example, the simplified task list combines many of the original tasks associated with engine room operations. If automation is introduced, it may eliminate or reduce the crew requirements for some of the original tasks, but it may not be clear how it affects the simplified task. Similarly, if a new crew complement is proposed that contains crew members who perform a different mix of activities compared to those in the original task list, then the simplified task list may not reflect their responsibilities and workload accurately. Specifically, it may not be possible to evaluate the effect of a new crew type that performs some of the tasks currently assigned to the engineering crew and some of those assigned to the deck crew. The simplified task list assumes that all the original tasks that are combined into single tasks are performed by either deck or engineering crew, making it impossible to identify the responsibilities of the new crew type using the simplified task list. These results show that the simplified task list undermines accuracy of analyses and that the simplifications limit the flexibility of CSEM.

4.3 Demonstration Analysis of an Operational Variable (Port Calls)

The purpose of CSEM is to examine the effect of operational variables on crew requirements. A sensitivity analysis of port calls examines this capability. Port calls impose an additional workload on the chief mate and others in the deck crew. The line handling and cargo operations are two labor intensive activities that might increase the average workhours of crew members as the number of port calls increase. Considering the total number and duration of tasks that need to be performed shows that port calls have a large effect on the total person-hours of tasks that need to be completed by the crew. Six port calls in 10 days involves 207.6 person-hours of tasks each day, while two port calls in 10 days involves 160.8 person-hours each day. Analysis using CSEM can show how the tasks are performed and how the workhours are distributed across the crew. A sensitivity analysis can also quantify the effect of these tasks over the voyage and the associated crew requirements.

Four levels of port call frequency were used to examine the effect of increasing the frequency of port calls on average workhours, workhour violations, and overall crew requirements. The baseline of two port calls in 10 days was compared to four and six port calls in 10 days and two port calls in 20 days. Tables 17 and 18 summarize the effect of increasing the frequency of port calls. Increasing the frequency of port calls increases the average workhours and the number of workhour limit violations.[24] Although the effects of port calls are not evenly distributed, with frequent port calls, the workhours of most watch types increase.[25] This suggests that port calls impose additional work on others beyond the additional cargo handling responsibilities assigned to the Chief Mate. This sensitivity analysis assumes that the nature of the port call is the same (same cargo loading or unloading durations) independent of the frequency of port calls. In reality, this is not the case. Before extensive analyses are done, the parameters of some tasks may require adjustment.

Table 17. Average workhours and violations for different port call frequencies.

Watch Type	2 ports in 20 days	Baseline 2 ports in 10 days	4 ports in 10 days	6 ports in 10 days
0 - 4	11.9 (5.0)	12.0 (3.8)	12.6 (10.2)	13.7 (13.3)
4 - 8	11.8 (6.5)	11.9 (6.5)	12.8 (11.3)	13.1 (12.9)
8 - 12	11.6 (5.1)	11.9 (4.9)	12.7 (8.6)	13.1 (11.3)
Command	10.5 (2.0)	10.6 (0.5)	10.5 (2.3)	12.0 (10.0)
Operational	10.0 (1.4)	10.5 (1.7)	10.5 (2.8)	11.2 (6.2)
Steward	12.1 (9.1)	12.9 (11.4)	12.5 (11.4)	12.5 (9.7)
Overall	11.6 (4.1)	11.8 (4.9)	12.1 (5.9)	12.8 (8.7)

Table 18. Task delay information for different port call frequencies.

Port Call Frequency	Average % of Tasks Delayed	Average Delay in Minutes	Average % of Tasks Not Performed
2 ports in 20 days	15.0	1082.0	2.2
2 ports in 10 days (Baseline)	15.6	453.8	4.0
4 ports in 10 days	14.0	558.2	8.6
6 ports in 10 days	12.5	612.6	11.7

Table 18 shows that increasing the frequency of port calls also affects the timely performance of tasks; increasing the frequency of port calls results in delayed tasks. The increasing task delays highlight the need for additional crew members. Table 18 shows that the average percent of tasks delayed per day is not sensitive to the frequency of port calls.[26] This lack of sensitivity parallels that seen in the analysis of input data uncertainty (Section 4.2.1). Table 18 shows that the average task delay is sensitive to the workload

[24] Violations, two factor repeated measures ANOVA; $p < 0.001$, $F(3,16) = 95.71$; Workhours, two factor repeated measures ANOVA; $p < 0.001$, $F(3,16) = 69.47$.
[25] Violations, two factor repeated measures ANOVA; $p < 0.001$, $F(15,80) = 6.16$; Workhours, two factor repeated measures ANOVA; $p < 0.001$, $F(15,80) = 5.20$.
[26] Average number of tasks delayed, two factor ANOVA; $p > 0.1$, $F(3,59) = 1.77$.

increase associated with port calls, but that it is also biased by the number of port calls.[27] Delayed tasks are dropped and not performed when the voyage phase changes. With frequent port calls, tasks will be dropped before a large delay can accumulate. Thus, task delay depends upon the workload the crew experiences (i.e., time between port calls) and the amount of time a delay can accumulate (i.e., time between voyage phase changes). Table 18 shows both of these effects, with the low workload voyage (the one with the greatest time between port calls) showing the largest delays. This result highlights the need for a careful analysis of measures and test conditions. This table shows that changing the overall voyage length can bias measures in unanticipated ways. The average percent of tasks not performed is very sensitive to increasing the frequency of port calls.[28] Like the average task delay, the average percent of tasks not performed depends on workload and frequency of port calls. The greater the number of port calls, the greater chance a task will be dropped rather than delayed.

Identifying the need for additional crew members requires a precise set of criteria. For this analysis, we assumed the following criteria for adding a crew member: 1) if any crew member had an average of more than 13 hours of work each day, or 2) if any crew member had an average of more than 10 workhour violations per day. A more detailed analysis of work/rest timelines of individual crew members must accompany these criteria. This detailed analysis shows the magnitude and duration of workhour violations and the incidence of extended periods without the opportunity for sleep. These criteria and the data in Table 15 suggest that increasing the frequency of port calls from two in 20 days to two in 10 days makes no difference in crew requirements; a ship serving two ports in 20 days does not need fewer crew than one serving two ports in 10 days. Increasing the frequency to four port calls in 10 days suggests a need for a 4 - 8 watchstander. Looking at the detailed data for the 4 - 8 watchstanders shows that the Mates and ABs become overloaded as port calls become more frequent. Adding one additional Mate is sufficient to relieve the overburdening of both the Mates and the ABs. Moving to six ports in 10 days shows the need for an additional Assistant Engineer for the 0 - 4 watch and a borderline need for more crew in the 8 - 12 and Command categories. Looking at the detailed data shows that the first assistant engineer needs additional assistance. Adding a watchstanding assistant engineer and making the first assistant engineer a day worker alleviate this problem.

The data in table 18 complement the data in table 17 and further illustrate the consequence of an inadequate crew. Unfortunately, the task delay information in table 18 does not provide a specific indication of additional crew requirements. Even an analysis of individual tasks might not indicate the need for additional crew members of a particular type, because several different crew members might be needed for any one task, making it difficult to identify which overloaded crew member caused the delay.

This analysis shows that CSEM can identify the increased demands associated with frequent port calls. Moreover, CSEM can identify specific crew members that need to be added to the crew. The results show

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[27] Average task delay, two factor ANOVA; $p < 0.0001$, $F(3,59) = 27.03$.

[28] Average percent of tasks not performed, two factor ANOVA; $p < 0.0001$, $F(3,59) = 469.27$.

little difference between two port calls in 10 days and two port calls in 20 days, but indicate a need for an additional mate when the frequency increases to four port calls in 10 days. Increasing port call frequency to six in 10 days leads to the need for an assistant engineer. Thus, the required crew increases from 25 to 27 with the addition of a mate and an assistant engineer.

5. CONCLUSIONS

This report addressed three objectives: validation of CSEM, investigation of the factors that influence its output, and demonstration that it can address operational variables that affect crew requirements. The findings suggest that each of these objectives has been met.

5.1 Validate: CSEM Can Produce an Accurate Evaluation of Crew Requirements

The findings show that several approaches validate CSEM's ability to provide a firm technical basis for crew size evaluation. At the most general level, CSEM meets or exceeds the initial requirements, which include the ability to:

- Examine a variety of operating procedures.
- Examine new crew structures and watchkeeping schedules.
- Accommodate new statutes.
- Consider emergency conditions.
- Record assumptions underlying data.

These requirements are met by a robust conceptual model that accurately reproduces actual shipboard activities. By an exhaustive set of tests, the validation shows that this conceptual model was successfully translated into a computer-based model. The computer model automates the overwhelming number of computations that would be required to create a paper and pencil simulation of shipboard activity using the conceptual model. A critical input to CSEM is task data. The findings validate the input data through comparison of interviews with crew members, examination of scheduled maintenance logs, and observations. The findings also provide the final validation of the model by comparing its output to records of actual shipboard activities. Comparing workhour estimates, logs of mariners work and sleep time, and patterns of work and rest shows that CSEM can capture differences between ship types and watch types to accurately predict workhours of mariners. These findings provide converging evidence that validates the ability of CSEM to evaluate crew requirements.

5.2 Investigate: Sensitivity Analyses Describe the Factors that Influence CSEM Predictions

The series of sensitivity analyses indicate how a variety of factors influence the output of CSEM. Analysis of input data uncertainty shows that CSEM is relatively robust and not overly sensitive to small errors in task time estimates. However, larger errors in task times can undermine the accuracy of CSEM. Because the analysis demonstrated a strong relationship between the workhour demands of tasks and the effect of data uncertainly, the need to collect more precise data can be targeted to high workhour demand tasks. This provides a practical tool to guide data collection so that it will provide the largest gain in CSEM accuracy, with a minimum cost.

Examining the internal model parameters showed that making CSEM's prediction of average sleep hours dependent on alertness, so that mariners do not sleep until they are tired, improves CSEM's predictions. This shows that the amount of sleep depends on factors beyond the total workhours. The analysis suggests two prerequisites for adequate sleep; the first is the availability of hours not occupied with work and the second is level of alertness conducive to sleep. This shows that the opportunity to sleep does not guarantee adequate sleep. The opportunity to sleep must correspond with a level of alertness at which the mariner can sleep.

The results also addressed potential simplifications to CSEM. Simplifying the task list undermines the accuracy and flexibility of CSEM. With the simplified task list, CSEM does not predict workhours as accurately, slightly overestimating crew requirements and failing to reflect the effect of watch and ship type. The poorer predictions, combined with the limited flexibility that accompanies a simplified task list, limits the utility of simplifying CSEM. The sensitivity analyses show how data uncertainty and simplifications can undermine CSEM accuracy, and how enhancing CSEM by including a model of alertness can improve CSEM's predictions of sleep.

5.3 Demonstrate: Show that the CSEM Can Evaluate How Crew Requirements Depend on Key Operational Variables

The purpose of CSEM is to evaluate the impact of operational variables on crew requirements. An analysis of a key operational variable (the frequency of port calls) showed that CSEM can support such an analysis. The findings demonstrate that CSEM is sensitive to an increase in the frequency of port calls, showing the need for additional support for cargo operations and line handling as the port call frequency increases. This analysis also demonstrates the need for a more comprehensive set of criteria to justify additions to a proposed crew. These results support the conclusion that CSEM can successfully identify when operational variables create the need for additional crew.

6. RECOMMENDATIONS

The findings and conclusions support several recommendations for the future of CSEM. These recommendations fall into three categories: 1) performing analyses of operational variables to generate guidelines for crew size evaluation, 2) enhancing CSEM and its output, and 3) applying CSEM to other Coast Guard initiatives.

6.1.1 Detailed Analysis of Key Operational Variables for Guideline Development

A review of the Coast Guard's current crew size evaluation practices suggests that CSEM can best support the Coast Guard as a tool to develop guidelines or a simple model (see Appendix E for details). In this role, CSEM would be used to analyze a wide range of issues and the results would be condensed into guidelines that could be included in the MSM and used independently of CSEM. By conducting analyses with CSEM and using the results to generate guidelines that can be disseminated to MSO and Headquarters personnel, CSEM can effectively support the crew size evaluation process through additions to current documents such as the MSM. This strategy provides the Coast Guard all the benefits and flexibility of CSEM without the burden of operating CSEM and analyzing its output.

The process of developing guidelines begins by working with Headquarters personnel to identify key operational variables. Candidate variables include:

- Port calls.
- Engine room automation.
- Shore-based support for cargo handling.
- Shore-based support for maintenance.
- Analysis of emergencies, such as crew incapacitation.
- Analysis of alternate crew structures such as permitting cross-over between the deck and engineering departments.

These key variables will then be analyzed using CSEM and the results will be compiled into rules, guidelines, or other decision aid. Because these decision aids are based on the results of a limited set of CSEM analyses, it is important to identify their limits and underling assumptions. Clearly specifying the limits of the decision aids will help ensure they are used correctly.

6.1.2 CSEM Enhancements: Develop More Precise Measures of Crew Adequacy

CSEM produces a great volume of data that describe the activities of crew members, the timing and sequence of tasks, and workhour and sleep histories. This information can be used to identify an inadequate crew through workhour violations, task delays, and average workhours. Depending on task priorities and allocation policies, symptoms of an inadequate crew may appear as task delays or excessive workhours. Currently, identifying the need for additional crew is a somewhat subjective process that considers task delays and workhour violations; however, more objective and precise criteria are needed. Improving the criteria requires a verification of the threshold for adding crew members. Improving the criteria might also involve a more detailed analysis and more precise criteria for considering delays of specific, high-priority tasks. For example, a delay in a single task, such as cargo loading, might indicate the need for an additional crew member or more shore-based support. Developing more precise criteria would make the output of CSEM more interpretable and the results more consistent.

6.1.3 CSEM Enhancements: Expand the Task Database to Include Towing Vessel Operations

Currently, the task data describe freighters and tankers; expanding this database to include other vessels, such as towing vessels, would enable CSEM to evaluate many more ship types and issues. The task list has been reviewed by representatives of the towing vessel industry and their comments have been used to tailor the task list so that it accurately describes their operations. The next step is to collect task data that describe towing vessels and build a database similar to that developed for tankers and freighters. Because towing vessel operations are more diverse, compared to deep draft operations, a critical step in this data collection effort will be to focus analysis on a particular type of towing operation. With task data describing towing vessel operations, it would be possible to validate CSEM more extensively and address crew size issues specific to the towing industry.

6.1.4 Applications to Other Coast Guard Initiatives: Use CSEM to Examine the Effect of Alternate Watchstanding Schedules

Because CSEM can predict workhours, track task delays, and identify crew requirements, it may provide useful input to other Coast Guard projects. In particular, CSEM could screen alternate watchstanding schedules to evaluate their feasibility. The high cost of examining alternate watchstanding schedules onboard actual ships makes it important to precisely design any comparison. CSEM can help with this design process by screening out unworkable alternatives before they are implemented. This information can maximize the efficiency of expensive field experiments.

An important criterion for alternate watchstanding schedules is their effect on sleep. Alternate watch schedules should provide for greater opportunities for sleep with fewer interruptions. Currently, CSEM uses a relatively simple algorithm to predict sleep times and alertness; improvements could make CSEM a more valuable tool. CSEM now predicts that mariners sleep if they are tired and not working, eating, or preparing for work. This algorithm predicts sleep times moderately well, but could easily be improved. Besides working and eating, mariners also enjoy limited recreational time and must attend to personal hygiene demands, such as washing clothes and showering. Predictions of sleep should include these other demands on a mariner's time. The level of alertness is likely an important determinant of sleep patterns; mariners are not likely to sleep if they are not tired. Therefore, the accuracy of the algorithms used to calculate alertness will affect the accuracy of predicted sleep times. The current alertness model calculates alertness based on circadian rhythms, which depend on the time of day, the amount of sleep the mariner has had, and the time since the last sleep. This algorithm and its parameters have only been validated for people with a single sleep episode. Watchstanders frequently have two or more sleep episodes, and the various watch schedules may interact with the circadian rhythm. Given the logbook data collected as part of a previous study (Sanquist, et al. 1996), it is possible to examine the role of these factors and enhance the algorithms to better estimate sleep times. These changes will enable the Coast Guard to examine a broad array of interventions aimed at reducing fatigue and increasing vessel safety.

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APPENDIX A: Task List and Task Definitions

This appendix describes the task lists used in the analyses. The detailed task list is presented first, followed by a simplified version. The specific sections of this appendix include:

- Summary of detailed task list.
- Definition of tasks in detailed task list.
- Summary of simplified task list.
- Definition of tasks in simplified task list.

Detailed Task List Summary

1. COMMAND AND CONTROL

1.1 Command, Control, and Coordination
1.2 Bridge Resource Management
1.3 Crew Performance Management and Maintenance

2. NAVIGATION

2.1 Bridge Watchkeeping
2.2 Lookout
2.3 Steering
2.4 Voyage Passage Planning
2.5 Weather Monitoring, Planning, and Reporting

3. COMMUNICATIONS

3.1 Long Range Radio Operations
3.2 Communication Record Keeping
3.3 Sound and Visual Signaling

4. ENGINEERING SYSTEM MONITORING, CONTROL AND OPERATIONS (MC&O)

4.1 Main Engine MC&O
4.2 Engineering Rounds and Record Keeping
4.3 Boiler MC&O
4.4 Fuel Oil Systems MC&O
4.5 Transfer Fuel Oil, Diesel Oil, and Lube Oil
4.6 Bunkering
4.7 Evaporator MC&O
4.8 Generator System MC&O
4.9 Electrical System MC&O
4.10 Inert Gas System MC&O
4.11 Heating, Ventalation, and AC MC&O
4.12 Sewage System MC&O

5. SCHEDULED MAINTENANCE AND TESTING (M&T)

5.1 Navigation Equipment M&T
5.2 Communication Equipment M&T
5.3 Vessel Fabric Maintenance
5.4 Cargo, Deck, and Hull Equipment M&T
5.5 Firefighting Equipment M&T
5.6 Lifesaving Equipment M&T
5.7 Tools and Test Equipment M&T
5.8 Plumbing M&T
5.9 Galley M&T

Engine Room

5.10 Main Engine M&T
5.11 Boiler M&T
5.12 Fuel Oil System M&T
5.13 Evaporator M&T
5.14 Generator M&T
5.15 Electrical System M&T
5.16 Pump M&T
5.17 Piping M&T
5.18 Steering Gear M&T
5.19 Inert Gas System M&T
5.20 Engine System Fabric Maintenance
5.21 Heating, Ventilation, and AC M&T
5.22 Sewage System M&T
5.23 Engine Room Cleaning

6. UNSCHEDULED MAINTENANCE AND REPAIR

6.1 Navigation Equipment Repair
6.2 Communication Equipment Repair
6.3 Vessel Fabric Repair
6.4 Cargo, Deck, and Hull Equipment Repair
6.5 Firefighting Equipment Repair
6.6 Lifesaving Equipment Repair
6.7 Tools and Test Equipment Repair
6.8 Plumbing Repair
6.9 Galley Repair

Engine Room

6.10 Main Engine Repair
6.11 Boiler Repair
6.12 Fuel Oil System Repair
6.13 Evaporator Repair
6.14 Generator Repair
6.15 Electrical System Repair
6.16 Pump Repair
6.17 Piping Repair
6.18 Steering Gear Repair
6.19 Inert Gas System Repair
6.20 Engine System Fabric Repair
6.21 Heating, Ventilation, and AC Repair
6.22 Sewage System Repair

7. EMERGENCY RESPONSE

7.1 Medical Care (for crew)
7.2 Engine Room Alarm
7.3 Crew Incapacitation
7.4 Galley Fire
7.5 Engine Room Fire
7.6 Steering Gear Failure
7.7 Oil Spill Response
7.8 Man Overboard
7.9 Abandon Ship

8. TRAINING AND DRILLS

8.1 Navigation Training
8.2 Engine Systems Training
8.3 Navigation Emergency Drills
8.4 Communication Systems Emergency Drills
8.5 Engine Room Emergency Drills
8.6 Fire and Lifeboat Drills
8.7 Man Overboard Drill
8.8 Oil Spill Response Drill

9. MANAGEMENT AND ADMINISTRATION

9.1 Deck Work Schedule Management
9.2 Chart Records and Corrections
9.3 Sign-On/Sign-Off Crew Members
9.4 Financial and Payroll Transactions
9.5 Deck Stores and Supplies
9.6 Drill Record Keeping and Reporting
9.7 Ship Yard Planning
9.8 Engine Room Historical Record Keeping
9.9 Engine Room Work Schedule Management
9.10 Engine Room Stores and Supplies
9.11 Medical Record Keeping, Logging, and Inventory
9.12 Medical Care

10. INTERNAL SHIP COMMUNICATIONS AND MEETINGS

10.1 Labor Relations
10.2 Shipboard Management Meetings
10.3 Safety Meetings
10.4 Quality of Work Life Meetings
10.5 Continuing Ed. and Professional Development
10.6 Promotion, Retention and Career Planning

11. REGULATORY COMPLIANCE

11.1 Deck Pollution Prevention Compliance
11.2 Engine Room Pollution Prevention Compliance
11.3 Documentation and Certification
11.4 Regulatory Pubs and Management Policy Manuals
11.5 Pre-Sail Testing/Fitness for Duty Testing
11.6 Communication Equipment, GMDDS Testing
11.7 Fire & Safety Inspections
11.8 Sanitary Inspections
11.9 Inspection Planning
11.10 Oversight Inspection Planning

12. CARGO RESPONSIBILITIES AND PASSENGER CARE

12.1 Cargo Planning
12.2 Cargo Load/Discharge Preparation
12.3 Cargo Equipment Test
12.4 Cargo Loading
12.5 Cargo Unloading
12.6 Cargo Maintenance
12.7 Cargo Monitoring and Record Keeping
12.8 Refrigerated Cargo Monitoring and Record Keeping
12.9 Hazardous Cargo Monitoring and Record Keeping
12.10 Tank Cleaning
12.11 Ballast Loading
12.12 Ballast Discharge or Transfer
12.13 Ballast Maintenance and Soundings
12.14 Stability Monitoring and Calculations
12.15 Passenger Assistance
12.16 Passenger Monitoring and Record Keeping

13. HOTEL SERVICES

13.1 Hotel Services Administration
13.2 Food Preparation
13.3 Food Service
13.4 Galley and Mess Room Cleaning
13.5 Bridge, Accommodation and Space Cleaning
13.6 Provisioning and Provisioning Management
13.7 Galley Stores and Supplies
13.8 Recreation

14. ARRIVAL, DEPARTURE AND PORT WATCHKEEPING

14.1 Departure Prepartion and Testing
14.2 Arrival Prepartion and Testing
14.3 Escort Vessel Interaction/Coordination
14.4 Docking
14.5 Undocking
14.6 Mooring to Bouy
14.7 Unmooring to Bouy
14.8 Anchoring
14.9 Weighing Anchor
14.10 Crane and Tug Operation
14.11 Monitor Vessel's Lines and Security
14.12 Intrusion Security Watch Operations
14.13 Stowaway Security Watch Operations

15. SPECIAL OPERATIONAL REQUIREMENTS

15.1 Underway Lightering Planning
15.2 Underway Lightering Loading
15.3 Underway Lightering Discharge
15.4 Underway and Vertical Replenishment Operations

Definitions for Detailed Task List

1. COMMAND AND CONTROL

1.1 Command, Control, and Coordination

The process of directing and managing the safety of the crew, vessel, passengers, cargo, and basic mission of the ship. This includes voyage planning; watchkeeping coordination and scheduling; route planning and review; cargo planning and review; propulsion systems planning and review; resource budgeting guidance and review; monitoring and control compliance with legislative bodies; and organizing the crew. This also includes all tasks required because of crew incapacitation or acts of God, as well as tasks that implement sound organization. This includes overall administration of the vessel, including management support and supervision of safe watchkeeping procedures and vessel operations.

1.2 Bridge Resource Management

The process of insuring that bridge resources are utilized in the safest and most effective fashion so as to facilitate efficient information and resource sharing on the bridge. This includes activities with the pilot aboard and debarked, activities to establish or clarify the master-pilot relationship, masters acting as pilots, and communication and operational activities required by effective use of bridge watch team personnel, including acts required by incapacitation of crew or acts of God.

1.3 Crew Performance Management and Maintenance

The process of insuring that crew performance is adequate for the requirements of the vessel and its voyage, including crew work hours management, and the management and prevention of fatigue and impairment of crew members.

2. NAVIGATION

2.1 Bridge Watchkeeping

The process of monitoring and controlling the vessel during the navigational duty period. This includes establishing the vessel's position, planning the ship's route, navigation, safety, maneuvering, anti-collision, administrative and management tasks, as well as tasks required by the practice of good seamanship. This may also include monitoring tows, integrated tug barges, and other vessels.

- **Vessel Performance Monitoring:** the process of monitoring vessel and hull performance, trim, stability calculations, and effecting adjustments to vessel course, speed, or voyage plan in order to enhance propulsion, steering, hull maintenance, or control systems performance, as well as to reduce vibration, stress, and foreign object collision. For vessels equipped with automated or intelligent systems, this includes monitoring vessel and system performance in order to insure that both are performing as required.

- **Navigation Equipment Monitoring:** the process of overseeing that navigation equipment is in proper working order. The process includes ensuring that alarms and indicators are functioning and that response procedures are followed in the event of alarms, inspection of daily time ticks and clock maintenance. For vessels equipped with automated or intelligent systems, this includes monitoring vessel and system performance in order to insure that both are performing as required.

- **Maneuvering and Collision Avoidance:** the process of ensuring that the vessel has no objects on its course or that it is not in the course of other vessels; in addition, the process of moving the vessel in response to other traffic or changes in the navigation situation.

- **Navigation Communications:** the process of creating and maintaining an efficient internal and external communication system in order to insure a safe navigational passage. Internal navigation communications may include conversations between the navigational watch officer and the master, those between the navigational watch officer and the navigational watch personnel, or between the navigational watch officer and the engineering personnel. In addition, external communications may include communications between the navigational watch team and other vessels including escort vessels and tugs, port authorities, pilots, and masters so as to insure a safe navigational transit. For arrivals and departures, and other operational periods, this may also include tasks required to separate simultaneous communications during busy periods, as well as communications required by personnel speaking different languages.

2.2 Lookout

The process of vigilant watching, hearing and reporting of navigation objects and obstacles under both favorable and adverse (e.g.. fog, rain, etc.) conditions to ensure safe passage through navigated routes.

2.3 Steering

The process of governing the course of a ship by controlling, directly or indirectly, the helm or the rudder. On vessels operating under automatic pilot, this may include monitoring the vessel's course and the steering system's execution of the automatically ordered course. On vessels operating "by hand," this includes directing the steering system so as to execute the ordered course, comparison of the ordered course with the executed course, and notification to the pilot, master or watch officer of the vessel's performance.

2.4 Voyage Passage Planning

The process of planning and preparing for a voyage in all phases; at dock, in restricted waters, and at sea. This includes reviewing the voyage schedule, preparation of orders and voyage plans, and monitoring of weather and route.

2.5 Weather Monitoring, Planning, and Reporting

The process of checking weather development and patterns, including using automated equipment in order to make sound forecasts. This includes weather monitoring, reporting, forecasting, and voyage and route planning in accordance with forecasts. On vessels equipped with automated weather prediction and planning systems, this may include review of weather predictions, forecasts voyage and route planning recommendations, as well as reconciliation of suggested and intended routes and plans. For vessels participating in weather observation and vessel rescue services, this may include reporting weather and vessel position(s).

3. COMMUNICATIONS

3.1 Long Range Radio Operations

The process of effecting long distance radio or satellite communications with shoreside management, regulatory agencies, vessel traffic control services, other vessels, or other shoreside parties, as well as maintaining an effective radio watch.

3.2 Communication Record Keeping

The process of recording all communication systems receipts and transmissions, including required radio watches and transmissions.

3.3 Sound and Visual Signaling

The process of using sound and visual signals to communicate. This can include use of whistles, bells, gongs, flags, sound powered telephones, flashing lights, semaphore, Aladaids, and signals from the International Code of Signals and the Rules of the Road.

4. ENGINEERING SYSTEM MONITORING, CONTROL, AND OPERATIONS (MC&O)

4.1 Main Engine MC&O

The process of ensuring main engines are functional and operational. This includes establishing performance objectives, planning and scheduling, preparation and coordination, start up and shut down, sustaining operations. This process may involve adjusting equipment systems and services to meet operating requirements, controlling malfunctions, monitoring and evaluating performance, and testing vital systems on arrival/departure. This also includes main engine control operations in attended and unattended machinery spaces.

4.2 Engineering Rounds and Record Keeping

The process of compiling and maintaining records on the main propulsion system equipment, including gathering data and information with respect to main engine and auxiliary systems status, performance, and response. This also involves checks for leaks and other malfunctions as the engineer moves through the machinery spaces.

4.3 Boiler MC&O

The process of monitoring, controlling, and operating the ship's boilers. This includes monitoring water levels and steam pressure, salinity and oxygen testing, cleaning, and control of the ship's boilers. Also included are preparations for lighting off, operation of the boiler(s) during maneuvering and at sea; and securing the boilers in port or during yard periods. This may also include the production of steam for whistles, sirens, deck equipment, heating, cooking, ventilation, refrigeration, and air conditioning.

4.4 Fuel Oil Systems MC&O

The process of operating, monitoring, and controlling the ship's fuel oil systems. This includes monitoring fuel levels; operating fuel pumps; fuel oil transfer operations; and fuel oil service activities associated with the main propulsion system. Specifically this may involve pumping and cleaning of the settling tank.

4.5 Transfer Fuel Oil, Diesel Oil, and Lube Oil

The process of transferring fuel oil, diesel oil, and lube oil in support of ship activities. This includes planning transfers, calculating and recalculating stability, effecting the transfer, and monitoring the fluid levels once achieved.

4.6 Bunkering

The process of taking on fuel (oil, coal, gas, etc.) used for the ship's propulsion and auxiliary machinery. This includes preparations for taking on fuel, pre-transfer agreements, pollution prevention and compliance activities, official notifications and communications between the bunkering facility or barge and vessel, the fuel transfer, and transfer completion activities.

4.7 Evaporator MC&O

The process of operating and controlling the ship's evaporators, which entails evaporating sea water for makeup feed water, drinking, cooking, and washing, and subsequent pumping of fresh water. Specifically this may include salinity testing.

4.8 Generator Systems MC&O

The process of operating the shipboard apparatus that convert mechanical energy into electrical energy. This includes control and operation of the primary, secondary, and emergency generator.

4.9 Electrical System MC&O

The process of insuring the electrical system is functional and operational, and of operating the electrical systems in support of the vessel's responsibilities. This includes operation and control of the ship's primary and auxiliary electrical systems, power distribution systems, circuit breakers, junction boxes, and auxiliary electrical systems.

4.10 Inert Gas Systems MC&O

The process of controlling and operating the ship's inert gas generating system. This includes testing, monitoring, and controlling inert gas output, production, and generation; recording and maintaining inert gas and gas free levels; and reporting inert gas and gas levels as required, and keeping the oil record book.

4.11 Heating, Ventilation, and AC MC&O

The process of operating and controlling the ship's heating, ventilation, and air conditioning systems, including associated air, steam, electrical, and mechanical ducting components of the system used to control conditions in occupied spaces.

4.12 Sewage System MC&O

The process of operating and controlling the ship's sewage system, including pumping, monitoring and controlling fresh and salt water for sanitary flushing requirements. This may also include periodic addition of required chemicals to the processing tanks.

5. SCHEDULED MAINTENANCE & TESTING (M&T)

5.1 Navigation Equipment M&T

The process of keeping navigation equipment in good operating condition. This includes routine maintenance checks, periodic and required testing, and preventive maintenance activities of the ship's electronic position fixing equipment, radars, ARPA's, collision avoidance systems, weather systems, facsimile machines and sensors, sextants, bearing circles, gyros, repeaters, magnetic compasses, electronic positioning equipment (e.g., SATNAV, LORAN-C, and GPS); and depth sounding equipment.

5.2 Communication Equipment M&T

The process of keeping communication systems in good operational condition. This includes preventative maintenance activities and required system testing of bridge and radio room (if fitted) communications equipment, including single sideband radio; radio frequency transmitters and receivers; UHF/VHF antenna, receivers, and transmitters; satellite communications equipment, facsimile machines, cellular phones, telex machines, computing systems and networks; and internal communications equipment such as VHF hand held speakers, Public Address Systems, sound powered phones, fire alarm systems, and general alarms.

5.3 Vessel Fabric Maintenance

The process of maintaining deck systems, bulkheads, structures, and fabric in good operational order by scraping, chipping, painting, applying coverings and monitoring the vessel fabric.

5.4 Cargo, Deck, and Hull Equipment M&T

The process of maintaining the ship's cargo equipment in operational condition. This includes preventative maintenance activities and periodic testing of the ship's cranes and hoists; lashing and security equipment;

cargo lines, pumps, valves, electrical systems, and testing equipment; container systems; electrical systems; container systems; refrigerated cargo systems and equipment; lights, pneumatic systems, crude oil washing (COW) systems equipment; closed gauging equipment, gauging indicators, other ancillary deck and hull equipment, and any additional cargo equipment carried, such as pilot hoists, gangways, winches, and anchor windlasses.

5.5 Firefighting Equipment M&T

The process of keeping firefighting equipment in proper working condition. This includes preventative maintenance activities, and periodic system testing of the fire main system, extinguisher, secondary fire protection systems, oxygen breathing apparatus, fire protective clothing, oxygen and explosimeters, combustible gas indicators, as well as hoses, valves, and nozzles.

5.6 Lifesaving Equipment M&T

The process of maintaining in good working order all lifesaving equipment aboard ship, including lifeboats, rafts, buoys, life jackets, exposure suits, line throwing apparatus, and other devices used for lifesaving purposes. This includes preventative maintenance activities and periodic lifesaving equipment tests.

5.7 Tools and Test Equipment M&T

The process of maintaining and testing shipboard tools and test equipment, including inert gas and gas free equipment, meters, test equipment, and manual and automated tools.

5.8 Plumbing M&T

The process of maintaining the sewage, potable water, and other elements of the plumbing system. This includes routine maintenance of valves, drains, and pipes associated with the plumbing system.

5.9 Galley M&T

The process of maintaining the galley area and equipment in good operational condition. This includes preventative maintenance, disinfecting, and testing of galley equipment, including stoves, ovens, galley and other electrical and/or mechanical appliances, as well as cleaning equipment.

Engine room

5.10 Main Engine M&T

The process of maintaining the main propulsion engine in good operational condition. This includes planning and scheduling, preparation and coordination for routine and preventative maintenance, testing, and rectifying faults and damage to verify that all components and functions of the main propulsion systems are operational.

5.11 Boiler M&T

The process of keeping the main or auxiliary/waste heat boilers in good operational condition. This includes maintenance and cleaning of the ship's boilers. Specifically this may include cleaning burners while in port. This may also include the maintenance of boilers in support of the production of steam for whistles, sirens, deck equipment, heating, cooking, and in some cases, refrigeration and air conditioning.

5.12 Fuel Oil System M&T

The process of keeping the fuel oil systems in good operational condition. This includes maintenance of fuel levels; checking and maintaining fuel pumps; maintenance of fuel oil transfer system and maintenance of fuel oil service activities associated with the main propulsion system.

5.13 Evaporator M&T

The process of keeping the evaporator(s) in good operating condition by maintaining evaporated sea water levels, amounts, and quality for make up feed water, drinking, cooking, and washing.

5.14 Generator M&T

The process of maintaining generators in good operational condition. This includes maintenance of the primary, secondary, and emergency generators, as well as required testing performed at periodic intervals.

5.15 Electrical System M&T

The process of maintaining the ship's electrical system in good operational condition. This includes maintenance and testing of the ship's primary and auxiliary electrical systems, power distribution systems, circuit breakers, junction boxes, and auxiliary electrical systems, as well as preparing and updating maintenance records to reflect the same in order to verify that the shipboard electrical systems and subsystems are functional.

5.16 Pump M&T

The process of keeping the pump system in good operational condition, in support of the vessel's main propulsion, fuel oil, fresh water, lube oil, diesel oil, fire main, and cargo systems.

5.17 Piping M&T

The process of keeping the piping system in good operational condition, in support of the vessel's main propulsion, fuel oil, fresh water, lube oil, diesel oil, fire main, and cargo systems.

5.18 Steering Gear M&T

The process of maintaining and testing steering gear systems. This includes the steering gear control stand, transmissive devices, controls and cards (if fitted), displays, and relays.

5.19 Inert Gas System M&T

The process of keeping the inert gas system in good operational condition, which includes testing, monitoring, and maintaining inert gas output, production, and generation; recording inert gas levels and maintaining gas free equipment.

5.20 Engine Systems Fabric Maintenance

The process of maintaining the engine systems' fabric, bulkheads, and structures. This includes preventative maintenance activities, including fabric painting, chipping, coating, covering, supporting, and care.

5.21 Heating, Ventilation, and AC M&T

The process of keeping the heating, ventilation, and air conditioning systems in good operational condition, including maintenance of the associated air, steam, electrical, and mechanical ducting components of the system used to control conditions in occupied spaces.

5.22 Sewage System M&T

The process of keeping the sewage system in good operating condition, including pumping monitoring and controlling fresh and salt water for sanitary flushing requirements so as to insure the systems operates correctly.

5.23 Engine Room Cleaning

The process of cleaning the engine room spaces.

6. UNSCHEDULED MAINTENANCE AND REPAIR

6.1 Navigation Equipment Repair

The process of repairing the ship's navigational equipment, including the ship's electronic position fixing equipment, radars, ARPA's, collision avoidance systems, weather sensing systems, facsimile machines and sensors; and depth sounding equipment, radar, navigational sensors, sextant, and bearing circles.

6.2 Communication Equipment Repair

The process of repairing communication equipment. This includes bridge radios, satellite communications systems, lifeboat radios and communications systems, cellular phones, VHF radios, telexes, facsimile, and associated computing equipment.

6.3 Vessel Fabric Repair

The process of repairing deck systems, bulkheads, structures, and vessel fabric.

6.4 Cargo, Deck, and Hull Equipment Repair

The process of repairing the ship's cargo equipment. This includes repair and test of the ship's cranes and hoists; lashing and security equipment; cargo lines, pumps, valves, and electrical systems; container systems; refrigerated cargo systems and equipment; lights and pneumatic systems; crude oil washing systems; gauging indicators; other ancillary deck and hull equipment; and any additional cargo equipment carried such as pilot hoists, gangways, winches, and anchor windlasses.

6.5 Firefighting Equipment Repair

The process of repairing damaged fire fighting equipment. This includes repair and test of the fire main system, extinguishers, secondary fire protection systems, oxygen breathing apparatus, fire protective clothing, oxygen and explosimeters, combustible gas indicators, as well as hoses, piping, pumps, valves, and nozzles.

6.6 Lifesaving Equipment Repair

The process of repairing lifesaving equipment, including lifeboats, rafts, buoys, jackets, line-throwing apparatus, and other devices used for lifesaving purposes.

6.7 Tools and Test Equipment Repair

The process of repairing shipboard tools and test equipment such as explosimeters and oxygen analyzers, inert gas and gas free test equipment; and manual and automated tools.

6.8 Plumbing Repair

The process of repairing the sewage, potable water, and other elements of the plumbing system. This includes clearing obstructed drains and toilets, replacing valves and pipes, and repairing faucets.

6.9 Galley Repair

The process of repairing the galley and equipment in the galley area such as stoves, ovens, electrical and/or mechanical appliances, and cleaning equipment.

Engine Room

6.10 Main Engine Repair

The process of repairing the main engine, including the prime mover, associated mechanical and electrical systems.

6.11 Boiler Repair

The process of repairing the boiler(s). This includes repair of the primary and secondary boilers, as well as the displays and test equipment indicating salinity and oxygen testing. Specifically this may include repairing a steam tube leak.

6.12 Fuel Oil Systems Repair

The process of repairing the fuel oil systems, including the repair of displays indicating fuel levels; fuel pumps; fuel oil transfer systems; and fuel oil service system components.

6.13 Evaporator Repair

The process of repairing the evaporator(s), in order to insure that evaporated sea water levels, amounts, and quality are adequate for make up feed water, drinking, cooking, and washing.

6.14 Generator Repair

The process of repairing the generator(s), including repair of the primary, secondary, and emergency generators, as well as follow-up testing performed at required periodic intervals.

6.15 Electrical System Repair

The process of repairing the ship's electrical systems. This includes repair of the ship's primary and auxiliary electrical systems, power distribution systems, circuit breakers, junction boxes, and auxiliary electrical systems, as well as preparing and updating maintenance records to reflect the same.

6.16 Pump Repair

The process of repairing the pump system in support of the vessel's main propulsion, fuel, fresh water, lube oil, diesel oil, fire main, and cargo systems.

6.17 Piping Repair

The process of repairing the piping system in support of the vessel's main propulsion, fuel, fresh water, lube oil, diesel oil, fire main, and cargo systems.

6.18 Steering Gear Repair

The process of repairing the steering gear system. This includes repair of the steering gear stand, transmissive devices, controls and cards (if fitted), displays, and relays.

6.19 Inert Gas System Repair

The process of repairing the inert gas system, which includes repairing, testing, and subsequent monitoring of inert gas output, production, generative systems, deck seals, scrubbers, gauges, monitors, piping, valves, and vents.

6.20 Engine Systems Fabric Repair

The process of repairing the engine systems' fabric, bulkheads, and structures.

6.21 Heating, Ventilation, and AC Repair

The process of repairing the refrigeration and air conditioning systems, including repair of the associated air, steam, electrical and mechanical ducting components of the system.

6.22 Sewage System Repair

The process of repairing the sewage system, including repair of associated pumps, displays, and controllers monitoring the fresh, gray, and salt water requirements.

7. EMERGENCY RESPONSE

7.1 Medical Care (for crew)

7.2 Engine Room Alarm

7.3 Crew Incapacitation

7.4 Galley Fire

7.5 Engine Room Fire

7.6 Steering Gear Failure

7.7 Oil Spill Response

7.8 Man Overboard

7.9 Abandon Ship

8. TRAINING AND DRILLS

8.1 Navigation Training

The process of training crew members in navigation practices and with navigation equipment. This includes equipment operations, procedure review, standard instructions, and maintenance of the technical library.

8.2 Engine Systems Training

The process of training crew members in main propulsion equipment operations and maintenance; auxiliary systems equipment and maintenance; and electrical systems equipment and maintenance. Training for these systems also include procedure review, standard instructions, and in the maintenance of the technical library.

8.3 Navigation Emergency Drills

The process of conducting emergency drills for navigation emergencies. This includes drills for equipment failure and malfunction, crew incapacitation, steering gear failure, procedure reviews, Global Marine Distress Safety System (GMDSS), development of emergency damage control procedures, search and rescue procedures, standard operating instructions review, discussions of expected and unexpected responses in navigational emergencies, and the development of best practices for navigational emergencies, and conducting safety meetings.

8.4 Communication Systems Emergency Drills

The process of conducting drills to train the crew to use radio services in the event of an emergency and to deal with the loss of communication media.

8.5 Engine Room Emergency Drills

The process of conducting emergency drills for engine room emergencies, including auxiliary systems and electrical systems drills. This includes drills for equipment failure and malfunction, crew incapacitation, procedure reviews, development of emergency damage control procedures, standard operating procedures review, discussion of expected and unexpected responses in engine room emergencies, and the development of best practices for engine room emergencies, and conducting engine safety meetings.

8.6 Fire and Lifeboat Drills

The process of simulating drills that train crew members for fire emergencies; and of conducting drills requiring the use of lifeboats for passengers and crew members in the event of a need to abandon ship.

8.7 Man Overboard Drill

The process of conducting simulated drills that train crew members in dealing with man overboard emergencies.

8.8 Oil Spill Response Drill

The process of conducting simulated drills that train crew members what actions to take if an oil spill occurs.

9. MANAGEMENT AND ADMINISTRATION

9.1 Deck Work Schedule Management

The process of identifying tasks and assigning work to members of the deck department. This also involves coordination of concurrent activities and verifying that tasks have been completed.

9.2 Chart Records and Corrections

The process of maintaining and correcting nautical charts. This includes inventorying charts, ordering required charts, and updating charts with information from Notices to Mariners, Light List and List of Lights corrections, as well as other nautical publications. With electronic charts, this may include review, maintenance, and correction of updates received through automated broadcast or electronic transmission.

9.3 Sign-On/Sign-Off Crew Members

The process of adding and deleting crew members to official crew lists.

9.4 Financial and Payroll Transactions

The process of paying crew members and the accompanying accounting record keeping. This includes maintaining the shipboard records of each crew member's financial records; transmitting these records shoreside; reconciliation of any discrepancies; determining individual, department and vessel performance measures; overtime accounting; and development of required periodic reports.

9.5 Deck Stores and Supplies

The process of storing, ordering, receiving, and handling deck materials for the voyage.

9.6 Drill Record Keeping and Reporting

The process of maintaining detailed information about drill results, lessons learned, and areas for improvement for tracking, management, and documentation for regulatory compliances.

9.7 Ship Yard Planning

The process of preparing the vessel, its personnel and facilities for shipyard periods. This includes meetings and conferences between shipboard department heads, individual department planning, interface and conferences with shoreside management and yard personnel, development of shipboard product and process specifications, cleaning and securing of vessel facilities prior to entering the yard, inventory of items and facilities prior to entrance into the yard, and coordination activities in order to insure yard period goals and objectives are met.

9.8 Main Engine Record Keeping - Historical

The process of compiling and maintaining records on the main propulsion system equipment, including machinery history, consumable stores inventory, personnel, and the planning of shipyard work.

9.9 Engine Room Work Schedule Management

The process of identifying tasks and assigning work to members of the engineering department. This also involves coordination of concurrent activities and verifying that tasks have been completed.

9.10 Engine Room Stores and Supplies

The process of storing, ordering, receiving, and handling materials for the voyage.

9.11 Medical Record Keeping, Logging, and Inventory

The process of maintaining medical records and organizing and managing medical care for crew members. Before, during, and following the administration of medical care to a crew member, medical records must be established and updated so as to establish a medical history for each crew member. This also includes establishing and maintaining records of drug and alcohol testing results for crew members.

9.12 Medical Care

The process of providing medical care for crew members. This includes first aid, diagnosis of medical problems which may include communicating via satellite with medical facilities for evaluation, administration of any required medication or antidote, and monitoring of the crew member's condition following administration of medical attention.

10. INTERNAL SHIP COMMUNICATIONS AND MEETINGS

10.1 Labor Relations

The process of dealing with labor concerns, providing avenues for labor to communicate to superiors, and handling disputes. This includes, among other tasks, conflict negotiation and dispute management activities, labor brokering and bartering activities, determination and management of crew workhours and workhours limits, and labor and personnel budgeting activities.

10.2 Shipboard Management Meetings

The process of holding meetings to discuss personnel, labor, safety and management issues. These can include formal and informal meetings between vessel department heads to coordinate personnel, resources, budgets, and schedule, as well as formal and informal members of crew members to coordinate, schedule, manage and direct work and resources aboard ship.

10.3 Safety Meetings

The process of holding meetings during which safety observations, practices, drills, and experiences are discussed, including identifying problem areas and developing recommendations for improvement. These meetings can be formal and informal exchanges of information, test results, drill feedback, and best practices; they can be ship-wide, or can be smaller discussions between department members, crew members assigned a particular task, or similar interested parties.

10.4 Quality of Work Life Meetings

The process of holding meetings to discuss shipboard life, conditions, practices, and changes to enhance any of these.

10.5 Continuing Ed., and Professional Development

The process of providing continuing education and professional development services for crew members. This can include formal high school equivalency, college, and graduate studies aboard ship; self-study programs for safety, management, engineering, or recreational interests; or the provision of tutors, educators, or scholars aboard for specific classes, tasks, or programs.

10.6 Promotion, Retention and Career Planning

The process of providing personnel promotion, retention, and career planning services aboard ship. This can include the use of self-study and educational materials aboard, ship; formal and informal conversations between crew members with respect to career planning and personnel retention; and formal programs introduced aboard ship for crew member promotion, retention, and career planning.

11. REGULATORY COMPLIANCE

11.1 Deck Pollution Prevention Compliance

The process of effecting deck pollution prevention regulatory compliance activities, including securing drains, valves, and pumps; insuring that equipment is tagged out and secure; installation of drip pans; and stationing of pollution prevention and clean-up equipment prior to fuel or cargo transfer. This also includes maintaining the safety of deck equipment, systems, and services; monitoring and controlling compliance with safety and environmental protection; developing deck emergency plans and procedures; and controlling deck pollution emergencies.

11.2 Engine Room Pollution Prevention Compliance

The process of effecting pollution prevention activities associated with the main propulsion system. This includes maintaining the safety of engineering equipment, systems, and services; monitoring and controlling compliance with safety and environmental protection; developing engineering emergency plans and procedures, and controlling engineering emergencies. This also includes securing drains, valves, and pumps; insuring that equipment is tagged out and secure, installation of drip pans; and stationing of pollution prevention and clean-up equipment prior to fuel or cargo transfer.

11.3 Documentation and Certification

The procedures for maintaining current required shipboard certification and documentation.

11.4 Regulatory Pubs and Management Policy Manuals

The process of maintaining a library of government publications and policy manuals.

11.5 Pre-Sail Testing/Fitness for Duty Testing

The process of checking and verifying that crew members are physically prepared for the impending voyage; this includes physical exams crew members must undergo to ensure members are fit to handle shipboard duties, which may include drug and alcohol testing, as required.

11.6 Communication Equipment, GMDSS Testing

The process of checking and verifying that communication equipment, including the Global Marine Distress Safety System (GMDSS), and EPIRB are functional. This also includes diagnostic and verification activities, and standalone and system interface testing.

11.7 Fire and Safety Inspections

The process of organizing and conducting workplace safety inspections and fire hazard inspections. This includes training of fire inspectors.

11.8 Sanitary Inspections

The process of conducting reviews and visual examinations of shipboard spaces so as to ensure their cleanliness. These activities include not only the visual examinations and walk around periods, but follow-up and unscheduled inspections, so as to ensure that all regulations regarding sanitary conditions are met.

11.9 Inspection Planning

The process of planning shipboard reviews and visual examinations of shipboard spaces so as to ensure their cleanliness. Planning activities can include review of safety and sanitary regulations, review of company sanitary, safety, and shipboard regulations, and development of pre- and post-inspection regimes so as to ensure that all regulations regarding safety and sanitary conditions are met.

11.10 Oversight Inspection Planning

The process of preparing the vessel, its personnel and facilities for periodic oversight inspections required by safety regulations. This includes meetings and conferences with shoreside management, and coordination of activities in order to insure oversight inspection and safety goals and objectives are met.

12. CARGO RESPONSIBILITIES AND PASSENGER CARE

12.1 Cargo Planning

The process of preparing the plan that details the quantities and description of the various items composing a ship's cargo in order to enable shipboard officers and agents at various ports to make necessary arrangements in advance for the expeditious discharge and loading of the cargo. This includes review of initial cargo assignments, review of the vessel voyage and route, review and development of the vessel transfer plan, and planning and coordination of terminal cargo operations. In addition, this includes development of revisions to and a final cargo/transfer plan, and required stability calculations.

12.2 Cargo Load/Discharge Preparation

The process of preparing cargo and cargo spaces for the carriage of cargo, including preparations for cargo load, preparations for cargo discharge, including laying out wires, ropes, shackles, manifolds, and tackle; breaking out cranes, hoists, derricks, and ground tackle; making the vessel ready for receipt/discharge of cargo including preparation; shipboard-terminal communications, including any pre-transfer conferences; safety and cargo equipment preparations; preparations for gas free operations and tank cooling on LNG/LPG vessels.

12.3 Cargo Equipment Test

The process of checking and verifying that cargo and cargo equipment is ready for transfer. This includes review of stowage and transfer plans, policies, and practices; reviews of cargo tests and amounts, inert gas systems, cargo monitoring systems, as well as checking and verifying actual cargo equipment: cranes, hoists, derricks, tackle, shackles, lines, ropes, wires, hoses, valves, pumps, manifolds, blanks, flanges, etc.

12.4 Cargo Loading

The process of loading cargo onto the ship including taking soundings and topping off. This includes loading cargo, including maintaining a cargo watch, stability calculations, checking lines, reading drafts, and ensuring cargo, personnel, and vessel integrity; and securing cargo and safety equipment following cargo loading.

12.5 Cargo Unloading

The process of discharging cargo from the ship. This includes cargo calculations, safety and cargo equipment preparations which includes hold/cargo tank; discharging cargo, including maintaining a cargo watch, stability calculations, checking lines, reading drafts, and ensuring cargo, personnel, and vessel integrity; and securing cargo and safety equipment following cargo discharge.

12.6 Cargo Maintenance

The process of checking, monitoring, and maintaining cargo carried on board, including cargo stability calculations. This includes daily (and more often, if required) checks of cargo carried, taking soundings, monitoring inert gas levels and oxygen, ballasting operations, daily checks of stowage and security arrangements, maintenance of cargo records documenting cargo maintenance, including refrigerated cargo equipment maintenance and inspection, and cargo transfer.

12.7 Cargo Monitoring and Record Keeping

The process of producing, maintaining, and updating records related to the vessel's cargo and its stability calculations. This includes cargo manifests, bills of lading, tonnage certificates, and other marine certificates as required, loading and discharge certificates, gas free certificates, inspection certificates, and cargo, stowage, and load plans.

12.8 Refrigerated Cargo Monitoring and Record Keeping

The process of insuring and documenting that the refrigerated cargo carried is secured, properly stowed, properly chilled or cooled, and handled.

12.9 Hazardous Cargo Monitoring and Record Keeping

The process of ensuring that hazardous cargo is stored and monitored in a safe fashion which includes producing, maintaining, and updating shipboard records of hazardous cargo, particularly documenting where the cargo was loaded, how handled, how protected, where stowed, how often checked, and safety and security precautions effected to insure the safety of the hazardous cargo.

12.10 Tank Cleaning

The process of cleaning cargo tanks. This includes safety preparations and post-cleaning inspections.

12.11 Ballast Loading

The process of taking on water in order to maintain the stability of the vessel and trim. Ballast loading includes monitoring tank cleaning for loading ballast, stability calculations, reviews of cargo, fuel, and water transfer plans, stability calculations and recalculations, taking soundings, and trimming the vessel so as to enhance vessel performance and fuel economy.

12.12 Ballast Discharge or Transfer

The process of discharging or transferring water in order to maintain the stability of the vessel and trim. Ballast discharge includes stability calculations, reviews of cargo, fuel, and water transfer plans, stability calculations and recalculations, taking soundings, monitoring of overboard discharge for oil pollution prevention, and trimming the vessel so as to enhance vessel performance and fuel economy.

12.13 Ballast Maintenance and Soundings

The process of monitoring and controlling the water taken on board in order to maintain the stability of the vessel and trim. This includes daily rounds to determine ballast levels, recording and comparing ballast levels, conducting stability calculations, and transferring ballast as necessary to maintain correct stability levels.

12.14 Stability Monitoring and Calculations

The process of maintaining and calculating the vessel's stability.

12.15 Passenger Assistance

The process of helping passengers on board the vessel--with physical access, hotel services, financial transactions, communications requirements, medical assistance, tourism services, etc.

12.16 Passenger Monitoring and Record Keeping

The process of producing, maintaining, and updating records of passenger information. This includes passenger manifests, medical information, personnel information, hotel service information, financial transactions, communications requirements, and customs clearance information.

13. HOTEL SERVICES

13.1 Hotel Services Administration

The process of supervising the activities of the steward department. This includes planning a meal schedule, tracking labor expenditures, and reporting the state of the department to the captain.

13.2 Food Preparation

The process of preparing a salad bar, soups, stocks, sauces, entrees, starches, vegetables, beverages, and deserts for the crew. It includes the drawing of appropriate stores for the preparation of meals.

13.3 Food Service

The process of serving prepared meals to the crew. This includes preparation of tables and mess areas, replenishing self-service stations, and delivery of meals to personnel confined to the bridge.

13.4 Galley and Mess Room Cleaning

The process of maintaining a sanitary environment for the preparation and consumption of meals. This includes cleaning of pots, pans, utensils, equipment, dishes, glasses, and silverware.

13.5 Bridge, Accommodation and Space Cleaning

The process of ensuring that accommodations are kept clean and orderly. This includes floor sweeping, washing, and maintenance; window and porthole cleaning; laundry services; linen changing and head cleaning; salt washdowns for the accommodation superstructures; and wipedown of the bridge, all accommodations and living spaces.

13.6 Provisioning and Provisioning Management

The process of ordering, inventorying, and planning galley, cleaning, and shipboard supplies and food so as to ensure adequate and contingency stores for the vessel's voyage.

13.7 Galley Stores and Supplies

The process of receiving, handling, and storing galley stores for the voyage.

13.8 Recreation

The process of insuring adequate recreational opportunities for crew members to pursue during free time. This includes time spent preparing, producing, planning and providing recreational activities as well as time preparing facilities and personnel for recreational activities.

14. ARRIVAL, DEPARTURE AND PORT WATCHKEEPING

14.1 Departure Preparation and Testing

The process of checking and verifying that the vessel and its crew are prepared for the impending departure of the vessel. This includes testing navigational equipment, steering gear, main and auxiliary propulsion equipment, storage of lines, cargo calculations, gauging of tanks, securing bulk cargoes, required drug and alcohol testing for crew members, and safety and cargo systems tests required prior to vessel departure.

14.2 Arrival Preparation and Testing

The process of checking and verifying that the vessel and its crew are prepared for the arrival of the vessel into a port. This includes testing navigational equipment, steering gear, main and auxiliary propulsion equipment, breaking lines out or "warming" winches and anchor windlasses, cleaning anchor, plugging, scrapping, and safety and cargo systems tests required prior to vessel arrival.

14.3 Escort Vessel Interaction/Coordination

The process of ensuring escort vessel interaction is facilitated. This includes tethering and untethering of escort vessels, escort vessel coordination conferences, standing by escort vessel lines, and monitoring escort vessel operations and interactions.

14.4 Docking

The process of assisting a vessel into a dock. This includes guidance of the vessel from just off the pier to the pier, and may or may not include the use of tugs. In addition, docking involves putting down the gangway, breaking out lines or "warming" winches and anchor windlasses, cleaning anchor, plugging, scrapping, securing the vessel to the shore with adequate lines, ropes, wires, etc., checking for vessel security, reading the vessel's draft at appropriate intervals, and insuring that the vessel is adequately lighted.

14.5 Undocking

The process of releasing the vessel from its shoreside securings. This includes guiding the vessel off the pier, and may or may not include the use of tugs. In addition, undocking involves securing the gangway, taking aboard and stowing the vessel's lines, ropes, wires, etc., checking for vessel security, gauging tanks, cargo calculations, securing bulk cargo, reading the vessel's draft if possible, and insuring that the vessel is properly lighted once away.

14.6 Mooring to Buoy

The process of securing a ship in a particular place by means of two or more anchors or cables which are made fast to a wharf, pier, another ship, the shore, or to anchored mooring buoys. This includes guidance of the vessel from just off the pier to the wharf, pier, or another ship; and may or may not include the use of tugs. In addition, mooring involves putting out a brow, gangway, or ladder for external access; breaking out lines or "warming" winches and anchor windlasses, clearing the anchor, plugging, scrapping, securing the vessel with adequate lines, ropes, wires, etc.; checking for vessel security; reading the vessel's draft at appropriate intervals; and insuring that the vessel is adequate lighted. This may also involve establishing a mooring watch and taking mooring bearings to ascertain the ship's position.

14.7 Unmooring from Buoy

The process of pulling in one anchor and casting off mooring lines from a wharf, pier, another ship, the shore, or from anchored mooring buoys. In addition, unmooring involves securing the gangway, brow or ladder used for external access; taking aboard and stowing the vessel's lines, ropes, wires, etc.; checking for vessel security; reading the vessel's draft if possible; and insuring that the vessel is properly lighted once away.

14.8 Anchoring

The process of dropping anchor, thus becoming attached to the ground at sea bed, and so rendered stationary. This includes preparation for anchor let go, clearing the hawse and chocks, checking the anchor brake, insuring that adequate and appropriate lights and day shapes are available to indicate that the vessel is lighted, and making the anchor security fast once anchored, and establishing an anchor watch to ensure that the vessel maintains its anchorage.

14.9 Weighing Anchor

The process of pulling in the anchor. This includes preparation for heaving in, including clearing the hawse and chocks, checking the anchor brake, insuring that adequate and appropriate lights and day shapes are available to indicate that the vessel is anchored, insuring that adequate power is available for heaving in, and making the anchor fast once the anchor is home.

14.10 Crane and Tug Operation

The process of directing and controlling the use of tug boats and floating cranes in support of shipboard work. This may include the use of tugs and cranes in the transfer of cargo between vessels, alongside a pier, from one station to another, or to bring passenger artifacts or shoreside equipment aboard.

14.11 Monitor Vessel's Lines and Security

The process of planning, preparing and insuring that the vessel is secure to its moorings, the pier, a wharf, or another ship. This includes watchkeeping in port, making frequent rounds throughout the vessel to determine her security, logging the results and findings of those rounds, checking the vessel's draft at periodic intervals, checking the security of deck scuppers watertight doors, and monitoring the weather so as to insure adequate vessel security, planning and preparation in the face of impending weather changes.

14.12 Intrusion Security Watch Operations

The process of planning, preparing and insuring that the vessel is secure from the intrusion of those who would do harm to crew members, pilfer cargo, or illegally remove cargo from the vessel while at sea, at anchor, at its berth, or its moorings.

14.13 Stowaway Security Watch Operations

The process of planning, preparing and insuring that the vessel is secure from the intrusion of those who would seek illegal passage aboard the vessel.

15. SPECIAL OPERATIONAL REQUIREMENTS

15.1 Underway Lightering Planning

The process of preparing the plan that details the quantities and description of the various items composing a ship's cargo in order to enable shipboard officers and agents at various ports to make necessary arrangements in advance for the expeditious discharge and loading of the cargo.

15.2 Underway Lightering Loading

The process of loading cargo onto the ship. This includes preparations for cargo load, including paying out wires, ropes, shackles and tackle; breaking out cranes, hoists, derricks, and ground tackle; making the vessel ready for receipt of cargo; shipboard-terminal communications, including any pre-transfer conferences; safety and cargo equipment preparations, and securing cargo and safety equipment following cargo loading.

15.3 Underway Lightering Discharge

The process of unloading cargo from the ship. This includes preparations for cargo discharge, including laying out wires ropes, shackles and tackle; breaking out cranes, hoists, derricks, and ground tackle gauging and cargo calculations; oil record book, making the vessel ready for cargo discharges; shipboard-terminal communications including any pre-discharge or transfer conferences; safety and cargo equipment preparations, and securing cargo and safety equipment following cargo discharge.

15.4 Underway and Vertical Replenishment Operations

The process of taking in cargo while underway, from either shipboard or airborne (vertical replenishment) sources. This includes required planning activities; pre-transfer conferences; replenishment maintenance, planning and preparation operations; personnel assistance with replenishment operations, including securing transfer hoses, security lines and safety watches, as well as disestablishing shipboard and airborne connections and safety watches.

Simplified Task Summary List

1. COMMAND AND CONTROL
1.1 Command, Control, and Coordination
2. NAVIGATION
2.1 Bridge Watchkeeping
2.2 Lookout
2.3 Steering
2.4 Voyage Planning
3. COMMUNICATIONS
3.1 Communication Operations
4. ENGINEERING SYSTEM MONITORING, CONTROL, AND OPERATIONS (MC&O)
4.1 Main Engine MC&O
4.2 Engineering Rounds and Record Keeping
4.3 Transfer Fuel Oil, Diesel Oil, and Lube Oil
4.4 Bunkering
5. SCHEDULED MAINTENANCE & TESTING (M&T)
5.1 Navigation & Communication Equipment M&T
5.2 Vessel Fabric Maintenance
5.3 Cargo, Deck, and Hull Equipment M&T
5.4 Safety Equipment
5.5 Tools and Test Equipment M&T
5.6 Engineering Systems
5.7 Engine Systems Fabric Maintenance
5.8 Engine Room Cleaning
6. UNSCHEDULED MAINTENANCE AND REPAIR
6.1 Navigation & Communication Equipment Repair
6.2 Vessel Fabric Repair
6.3 Cargo, Deck, and Hull Equipment Repair
6.4 Safety Equipment Repair
6.5 Tools and Test Equipment Repair
6.6 Engineering Systems Repair
6.7 Engine Systems Fabric Repair
7. EMERGENCY RESPONSE
7.1 Medical Care (for crew)
7.2 Engine Room Alarm
7.3 Crew Incapacitation
7.4 Galley Fire
7.5 Engine Room Fire
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12.12 Passenger Assistance
12.13 Passenger Monitoring and Record Keeping
13. HOTEL SERVICES
13.1 Hotel Services Administration
13.2 Food Preparation, Service and Galley Cleaning
13.3 Bridge, Accommodation and Space Cleaning
13.4 Provisioning and Provisioning Management
13.5 Galley Stores and Supplies
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14. ARRIVAL, DEPARTURE AND PORT WATCHKEEPING
14.1 Departure Preparation and Testing
14.2 Arrival Preparation and Testing
14.3 Escort Vessel Interaction/Coordination
14.4 Docking
14.5 Undocking
14.6 Mooring to Buoy
14.7 Unmooring from Buoy
14.8 Anchoring
14.9 Weighing Anchor
14.10 Crane and Tug Operation
14.11 Monitor Vessel's Lines and Security
15. SPECIAL OPERATIONAL REQUIREMENTS
15.1 Underway Lightering Planning
15.2 Underway Lightering Loading
15.3 Underway Lightering Discharge
15.4 Underway and Vertical Replenishment Operations

Definitions for Simplified Task List

1. COMMAND AND CONTROL

1.1 Command, Control, and Coordination

The process of directing and managing the safety of the crew, vessel, passengers, cargo, and basic mission of the ship. This includes voyage planning; watchkeeping coordination and scheduling; route planning and review; cargo planning and review; propulsion systems planning and review; resource budgeting guidance and review; monitoring and control compliance with legislative bodies; and organizing the crew. This also includes all tasks required because of crew incapacitation or acts of God, as well as tasks that implement sound organization. This includes overall administration of the vessel, including management support and supervision of safe watchkeeping procedures and vessel operations.

The process of insuring that bridge resources are utilized in the safest and most effective fashion so as to facilitate efficient information and resource sharing on the bridge. This includes activities with the pilot aboard and debarked, activities to establish or clarify the master-pilot relationship, masters acting as pilots, and communication and operational activities required by effective use of bridge watch team personnel, including acts required by incapacitation of crew or acts of God.

The process of insuring that crew performance is adequate for the requirements of the vessel and its voyage, including crew work hours management, and the management and prevention of fatigue and impairment of crew members.

2. NAVIGATION

2.1 Bridge Watchkeeping

The process of monitoring and controlling the vessel during the navigational duty period. This includes establishing the vessel's position, planning the ship's route, navigation, safety, maneuvering, anti-collision, administrative and management tasks, as well as tasks required by the practice of good seamanship. This may also include monitoring tows, integrated tug barges, and other vessels.

- **Vessel Performance Monitoring:** the process of monitoring vessel and hull performance, trim, stability calculations, and effecting adjustments to vessel course, speed, or voyage plan in order to enhance propulsion, steering, hull maintenance, or control systems performance, as well as to reduce vibration, stress, and foreign object collision. For vessels equipped with automated or intelligent systems, this includes monitoring vessel and system performance in order to insure that both are performing as required.

- **Navigation Equipment Monitoring:** the process of overseeing that navigation equipment is in proper working order. The process includes ensuring that alarms and indicators are functioning and that response procedures are followed in the event of alarms, inspection of daily time ticks and clock maintenance. For vessels equipped with automated or intelligent systems, this includes monitoring vessel and system performance in order to insure that both are performing as required.

- **Maneuvering and Collision Avoidance:** the process of ensuring that the vessel has no objects on its course or that it is not in the course of other vessels; in addition, the process of moving the vessel in response to other traffic or changes in the navigation situation.

- **Navigation Communications:** the process of creating and maintaining an efficient internal and external communication system in order to insure a safe navigational passage. Internal navigation communications may include conversations between the navigational watch officer and the master, those between the navigational watch officer and the navigational watch personnel, or between the navigational watch officer and the engineering personnel. In addition, external communications may include communications between the navigational watch team and other vessels including escort vessels and tugs, port authorities, pilots, and masters so as to insure a safe navigational transit. For arrivals and departures, and other operational periods, this may also include tasks required to separate simultaneous communications during busy periods, as well as communications required by personnel speaking different languages.

2.2 Lookout

The process of vigilant watching, hearing and reporting of navigation objects and obstacles under both favorable and adverse (e.g.. fog, rain, etc.) conditions to ensure safe passage through navigated routes.

2.3 Steering

The process of governing the course of a ship by controlling, directly or indirectly, the helm or the rudder. On vessels operating under automatic pilot, this may include monitoring the vessel's course and the steering system's execution of the automatically ordered course. On vessels operating "by hand," this includes directing the steering system so as to execute the ordered course, comparison of the ordered course with the executed course, and notification to the pilot, master or watch officer of the vessel's performance.

2.4 Voyage Planning

The process of planning and preparing for a voyage in all phases; at dock, in restricted waters, and at sea. This includes reviewing the voyage schedule, preparation of orders and voyage plans, and monitoring of weather and route.

The process of checking weather development and patterns, including using automated equipment in order to make sound forecasts. This includes weather monitoring, reporting, forecasting, and voyage and route planning in accordance with forecasts. On vessels equipped with automated weather prediction and planning systems, this may include review of weather predictions, forecasts voyage and route planning recommendations, as well as reconciliation of suggested and intended routes and plans. For vessels participating in weather observation and vessel rescue services, this may include reporting weather and vessel position(s).

3. COMMUNICATIONS

3.1 Communication Operations

The process of effecting long distance radio or satellite communications with shoreside management, regulatory agencies, vessel traffic control services, other vessels, or other shoreside parties, as well as maintaining an effective radio watch.

The process of recording all communication systems receipts and transmissions, including required radio watches and transmissions.

The process of using sound and visual signals to communicate. This can include use of whistles, bells, gongs, flags, sound powered telephones, flashing lights, semaphore, Aladaids, and signals from the International Code of Signals and the Rules of the Road.

4. ENGINEERING SYSTEM MONITORING, CONTROL, AND OPERATIONS (MC&O)

4.1 Main Engine MC&O

The process of ensuring main engines are functional and operational. This includes establishing performance objectives, planning and scheduling, preparation and coordination, start up and shut down, sustaining operations. This process may involve adjusting equipment systems and services to meet operating requirements, controlling malfunctions, monitoring and evaluating performance, and testing vital systems on arrival/departure. This also includes main engine control operations in attended and unattended machinery spaces.

4.2 Engineering Rounds and Record Keeping

The process of compiling and maintaining records on the main propulsion system equipment, including gathering data and information with respect to main engine and auxiliary systems status, performance, and response. This also involves checks for leaks and other malfunctions as the engineer moves through the machinery spaces.

The process of monitoring, controlling, and operating the ship's boilers. This includes monitoring water levels and steam pressure, salinity and oxygen testing, cleaning, and control of the ship's boilers. Also included are preparations for lighting off, operation of the boiler(s) during maneuvering and at sea; and securing the boilers in port or during yard periods. This may also include the production of steam for whistles, sirens, deck equipment, heating, cooking, ventilation, refrigeration, and air conditioning.

The process of operating, monitoring, and controlling the ship's fuel oil systems. This includes monitoring fuel levels; operating fuel pumps; fuel oil transfer operations; and fuel oil service activities associated with the main propulsion system. Specifically this may involve pumping and cleaning of the settling tank.

The process of operating and controlling the ship's evaporators, which entails evaporating sea water for makeup feed water, drinking, cooking, and washing, and subsequent pumping of fresh water. Specifically this may include salinity testing.

The process of operating the shipboard apparatus that convert mechanical energy into electrical energy. This includes control and operation of the primary, secondary, and emergency generator.

The process of insuring the electrical system is functional and operational, and of operating the electrical systems in support of the vessel's responsibilities. This includes operation and control of the ship's primary and auxiliary electrical systems, power distribution systems, circuit breakers, junction boxes, and auxiliary electrical systems.

The process of controlling and operating the ship's inert gas generating system. This includes testing, monitoring, and controlling inert gas output, production, and generation; recording and maintaining inert gas and gas free levels; and reporting inert gas and gas levels as required, and keeping the oil record book.

The process of operating and controlling the ship's heating, ventilation, and air conditioning systems, including associated air, steam, electrical, and mechanical ducting components of the system used to control conditions in occupied spaces.

The process of operating and controlling the ship's sewage system, including pumping, monitoring and controlling fresh and salt water for sanitary flushing requirements. This may also include periodic addition of required chemicals to the processing tanks.

4.3 Transfer Fuel Oil, Diesel Oil, and Lube Oil

The process of transferring fuel oil, diesel oil, and lube oil in support of ship activities. This includes planning transfers, calculating and recalculating stability, effecting the transfer, and monitoring the fluid levels once achieved.

4.4 Bunkering

The process of taking on fuel (oil, coal, gas, etc.) used for the ship's propulsion and auxiliary machinery.

This includes preparations for taking on fuel, pre-transfer agreements, pollution prevention and compliance activities, official notifications and communications between the bunkering facility or barge and vessel, the fuel transfer, and transfer completion activities.

5. SCHEDULED MAINTENANCE & TESTING (M&T)

5.1 Navigation & Communication Equipment M&T

The process of keeping navigation equipment in good operating condition. This includes routine maintenance checks, periodic and required testing, and preventive maintenance activities of the ship's electronic position fixing equipment, radars, ARPA's, collision avoidance systems, weather systems, facsimile machines and sensors, sextants, bearing circles, gyros, repeaters, magnetic compasses, electronic positioning equipment (e.g., SATNAV, LORAN-C, and GPS); and depth sounding equipment.

The process of keeping communication systems in good operational condition. This includes preventative maintenance activities and required system testing of bridge and radio room (if fitted) communications equipment, including single sideband radio; radio frequency transmitters and receivers; UHF/VHF antenna, receivers, and transmitters; satellite communications equipment, facsimile machines, cellular phones, telex machines, computing systems and networks; and internal communications equipment such as VHF hand held speakers, Public Address Systems, sound powered phones, fire alarm systems, and general alarms.

5.2 Vessel Fabric Maintenance

The process of maintaining deck systems, bulkheads, structures, and fabric in good operational order by scraping, chipping, painting, applying coverings and monitoring the vessel fabric.

5.3 Cargo, Deck, and Hull Equipment M&T

The process of maintaining the ship's cargo equipment in operational condition. This includes preventative maintenance activities and periodic testing of the ship's cranes and hoists; lashing and security equipment; cargo lines, pumps, valves, electrical systems, and testing equipment; container systems; electrical systems; container systems; refrigerated cargo systems and equipment; lights, pneumatic systems, crude oil washing (COW) systems equipment; closed gauging equipment, gauging indicators, other ancillary deck and hull equipment, and any additional cargo equipment carried, such as pilot hoists, gangways, winches, and anchor windlasses.

5.4 Safety Equipment M&T

The process of keeping firefighting equipment in proper working condition. This includes preventative maintenance activities, and periodic system testing of the fire main system, extinguisher, secondary fire protection systems, oxygen breathing apparatus, fire protective clothing, oxygen and explosimeters, combustible gas indicators, as well as hoses, valves, and nozzles.

The process of maintaining in good working order all lifesaving equipment aboard ship, including lifeboats, rafts, buoys, life jackets, exposure suits, line throwing apparatus, and other devices used for lifesaving purposes. This includes preventative maintenance activities and periodic lifesaving equipment tests.

5.5 Tools and Test Equipment M&T

The process of maintaining and testing shipboard tools and test equipment, including inert gas and gas free equipment, meters, test equipment, and manual and automated tools.

5.6 Engineering Systems M&T

The process of maintaining the sewage, potable water, and other elements of the plumbing system. This includes routine maintenance of valves, drains, and pipes associated with the plumbing system.

The process of maintaining the galley area and equipment in good operational condition. This includes preventative maintenance, disinfecting, and testing of galley equipment, including stoves, ovens, galley and other electrical and/or mechanical appliances, as well as cleaning equipment.

Engine room

The process of maintaining the main propulsion engine in good operational condition. This includes planning and scheduling, preparation and coordination for routine and preventative maintenance, testing, and rectifying faults and damage to verify that all components and functions of the main propulsion systems are operational.

The process of keeping the main or auxiliary/waste heat boilers in good operational condition. This includes maintenance and cleaning of the ship's boilers. Specifically this may include cleaning burners while in port. This may also include the maintenance of boilers in support of the production of steam for whistles, sirens, deck equipment, heating, cooking, and in some cases, refrigeration and air conditioning.

The process of keeping the fuel oil systems in good operational condition. This includes maintenance of fuel levels; checking and maintaining fuel pumps; maintenance of fuel oil transfer system and maintenance of fuel oil service activities associated with the main propulsion system.

The process of keeping the evaporator(s) in good operating condition by maintaining evaporated sea water levels, amounts, and quality for make up feed water, drinking, cooking, and washing.

The process of maintaining generators in good operational condition. This includes maintenance of the primary, secondary, and emergency generators, as well as required testing performed at periodic intervals.

The process of maintaining the ship's electrical system in good operational condition. This includes maintenance and testing of the ship's primary and auxiliary electrical systems, power distribution systems, circuit breakers, junction boxes, and auxiliary electrical systems, as well as preparing and updating maintenance records to reflect the same in order to verify that the shipboard electrical systems and subsystems are functional.

The process of keeping the pump system in good operational condition, in support of the vessel's main propulsion, fuel oil, fresh water, lube oil, diesel oil, fire main, and cargo systems.

The process of keeping the piping system in good operational condition, in support of the vessel's main propulsion, fuel oil, fresh water, lube oil, diesel oil, fire main, and cargo systems.

The process of maintaining and testing steering gear systems. This includes the steering gear control stand, transmissive devices, controls and cards (if fitted), displays, and relays.

The process of keeping the inert gas system in good operational condition, which includes testing, monitoring, and maintaining inert gas output, production, and generation; recording inert gas levels and maintaining gas free equipment.

The process of keeping the heating, ventilation, and air conditioning systems in good operational condition, including maintenance of the associated air, steam, electrical, and mechanical ducting components of the system used to control conditions in occupied spaces.

The process of keeping the sewage system in good operating condition, including pumping monitoring and controlling fresh and salt water for sanitary flushing requirements so as to insure the systems operates correctly.

5.7 Engine Systems Fabric Maintenance

The process of maintaining the engine systems' fabric, bulkheads, and structures. This includes preventative maintenance activities, including fabric painting, chipping, coating, covering, supporting, and care.

5.8 Engine Room Cleaning

The process of cleaning the engine room spaces.

6. UNSCHEDULED MAINTENANCE AND REPAIR

6.1 Navigation & Communication Equipment Repair

The process of repairing the ship's navigational equipment, including the ship's electronic position fixing equipment, radars, ARPA's, collision avoidance systems, weather sensing systems, facsimile machines and sensors; and depth sounding equipment, radar, navigational sensors, sextant, and bearing circles.

The process of repairing communication equipment. This includes bridge radios, satellite communications systems, lifeboat radios and communications systems, cellular phones, VHF radios, telexes, facsimile, and associated computing equipment.

6.2 Vessel Fabric Repair

The process of repairing deck systems, bulkheads, structures, and vessel fabric.

6.3 Cargo, Deck, and Hull Equipment Repair

The process of repairing the ship's cargo equipment. This includes repair and test of the ship's cranes and hoists; lashing and security equipment; cargo lines, pumps, valves, and electrical systems; container systems; refrigerated cargo systems and equipment; lights and pneumatic systems; crude oil washing systems; gauging indicators; other ancillary deck and hull equipment; and any additional cargo equipment carried such as pilot hoists, gangways, winches, and anchor windlasses.

6.4 Safety Equipment Repair

The process of repairing damaged fire fighting equipment. This includes repair and test of the fire main system, extinguishers, secondary fire protection systems, oxygen breathing apparatus, fire protective clothing, oxygen and explosimeters, combustible gas indicators, as well as hoses, piping, pumps, valves, and nozzles.

The process of repairing lifesaving equipment, including lifeboats, rafts, buoys, jackets, line-throwing apparatus, and other devices used for lifesaving purposes.

6.5 Tools and Test Equipment Repair

The process of repairing shipboard tools and test equipment such as explosimeters and oxygen analyzers, inert gas and gas free test equipment; and manual and automated tools.

6.6 Engineering Systems Repair

The process of repairing the sewage, potable water, and other elements of the plumbing system. This includes clearing obstructed drains and toilets, replacing valves and pipes, and repairing faucets.

The process of repairing the galley and equipment in the galley area such as stoves, ovens, electrical and/or mechanical appliances, and cleaning equipment.

Engine Room

The process of repairing the main engine, including the prime mover, associated mechanical and electrical systems.

The process of repairing the boiler(s). This includes repair of the primary and secondary boilers, as well as the displays and test equipment indicating salinity and oxygen testing. Specifically this may include repairing a steam tube leak.

The process of repairing the fuel oil systems, including the repair of displays indicating fuel levels; fuel pumps; fuel oil transfer systems; and fuel oil service system components.

The process of repairing the evaporator(s), in order to insure that evaporated sea water levels, amounts, and quality are adequate for make up feed water, drinking, cooking, and washing.

The process of repairing the generator(s), including repair of the primary, secondary, and emergency generators, as well as follow-up testing performed at required periodic intervals.

The process of repairing the ship's electrical systems. This includes repair of the ship's primary and auxiliary electrical systems, power distribution systems, circuit breakers, junction boxes, and auxiliary electrical systems, as well as preparing and updating maintenance records to reflect the same.

The process of repairing the pump system in support of the vessel's main propulsion, fuel, fresh water, lube oil, diesel oil, fire main, and cargo systems.

The process of repairing the piping system in support of the vessel's main propulsion, fuel, fresh water, lube oil, diesel oil, fire main, and cargo systems.

The process of repairing the steering gear system. This includes repair of the steering gear stand, transmissive devices, controls and cards (if fitted), displays, and relays.

The process of repairing the inert gas system, which includes repairing, testing, and subsequent monitoring of inert gas output, production, generative systems, deck seals, scrubbers, gauges, monitors, piping, valves, and vents.

The process of repairing the refrigeration and air conditioning systems, including repair of the associated air, steam, electrical and mechanical ducting components of the system.

The process of repairing the sewage system, including repair of associated pumps, displays, and controllers monitoring the fresh, gray, and salt water requirements.

6.7 Engine Systems Fabric Repair

The process of repairing the engine systems' fabric, bulkheads, and structures.

7. EMERGENCY RESPONSE

7.1 Medical Care (for crew)

7.2 Engine Room Alarm

7.3 Crew Incapacitation

7.4 Galley Fire

7.5 Engine Room Fire

7.6 Steering Gear Failure

7.7 Oil Spill Response

7.8 Man Overboard

7.9 Abandon Ship

8. TRAINING AND DRILLS

8.1 Navigation Training

The process of training crew members in navigation practices and with navigation equipment. This includes equipment operations, procedure review, standard instructions, and maintenance of the technical library.

The process of conducting emergency drills for navigation emergencies. This includes drills for equipment failure and malfunction, crew incapacitation, steering gear failure, procedure reviews, Global Marine Distress Safety System (GMDSS), development of emergency damage control procedures, search and rescue procedures, standard operating instructions review, discussions of expected and unexpected responses in navigational emergencies, and the development of best practices for navigational emergencies, and conducting safety meetings.

8.2 Engine Systems Training

The process of training crew members in main propulsion equipment operations and maintenance; auxiliary systems equipment and maintenance; and electrical systems equipment and maintenance. Training for these systems also include procedure review, standard instructions, and in the maintenance of the technical library.

The process of conducting emergency drills for engine room emergencies, including auxiliary systems and electrical systems drills. This includes drills for equipment failure and malfunction, crew incapacitation, procedure reviews, development of emergency damage control procedures, standard operating procedures review, discussion of expected and unexpected responses in engine room emergencies, and the development of best practices for engine room emergencies, and conducting engine safety meetings.

8.3 Communication Systems Emergency Drills

The process of conducting drills to train the crew to use radio services in the event of an emergency and to deal with the loss of communication media.

8.4 Fire and Lifeboat Drills

The process of simulating drills that train crew members for fire emergencies; and of conducting drills requiring the use of lifeboats for passengers and crew members in the event of a need to abandon ship.

The process of conducting simulated drills that train crew members in dealing with man overboard emergencies.

8.5 Oil Spill Response Drill

The process of conducting simulated drills that train crew members what actions to take if an oil spill occurs.

9. MANAGEMENT AND ADMINISTRATION

9.1 Deck Personnel Management

The process of identifying tasks and assigning work to members of the deck department. This also involves coordination of concurrent activities and verifying that tasks have been completed.

The process of adding and deleting crew members to official crew lists.

The process of paying crew members and the accompanying accounting record keeping. This includes maintaining the shipboard records of each crew member's financial records; transmitting these records shoreside; reconciliation of any discrepancies; determining individual, department and vessel performance measures; overtime accounting; and development of required periodic reports.

The process of maintaining detailed information about drill results, lessons learned, and areas for improvement for tracking, management, and documentation for regulatory compliances.

9.2 Chart Records and Corrections

The process of maintaining and correcting nautical charts. This includes inventorying charts, ordering required charts, and updating charts with information from Notices to Mariners, Light List and List of Lights corrections, as well as other nautical publications. With electronic charts, this may include review, maintenance, and correction of updates received through automated broadcast or electronic transmission.

9.3 Deck Stores and Supplies

The process of storing, ordering, receiving, and handling deck materials for the voyage.

9.4 Engine Room Maintenance Work Schedule Management

The process of preparing the vessel, its personnel and facilities for shipyard periods. This includes meetings and conferences between shipboard department heads, individual department planning, interface and conferences with shoreside management and yard personnel, development of shipboard product and process specifications, cleaning and securing of vessel facilities prior to entering the yard, inventory of items and facilities prior to entrance into the yard, and coordination activities in order to insure yard period goals and objectives are met.

The process of compiling and maintaining records on the main propulsion system equipment, including machinery history, consumable stores inventory, personnel, and the planning of shipyard work.

The process of identifying tasks and assigning work to members of the engineering department. This also involves coordination of concurrent activities and verifying that tasks have been completed.

The process of storing, ordering, receiving, and handling materials for the voyage.

9.5 Medical Care, Record Keeping, Logging & Inventory

The process of maintaining medical records and organizing and managing medical care for crew members. Before, during, and following the administration of medical care to a crew member, medical records must be established and updated so as to establish a medical history for each crew member. This also includes establishing and maintaining records of drug and alcohol testing results for crew members.

The process of providing medical care for crew members. This includes first aid, diagnosis of medical problems which may include communicating via satellite with medical facilities for evaluation, administration of any required medication or antidote, and monitoring of the crew member's condition following administration of medical attention.

10. INTERNAL SHIP COMMUNICATIONS AND MEETINGS

10.1 Internal Ship Communications

The process of dealing with labor concerns, providing avenues for labor to communicate to superiors, and handling disputes. This includes, among other tasks, conflict negotiation and dispute management activities, labor brokering and bartering activities, determination and management of crew workhours and workhours limits, and labor and personnel budgeting activities.

The process of holding meetings to discuss personnel, labor, safety and management issues. These can include formal and informal meetings between vessel department heads to coordinate personnel, resources, budgets, and schedule, as well as formal and informal members of crew members to coordinate, schedule, manage and direct work and resources aboard ship.

The process of holding meetings during which safety observations, practices, drills, and experiences are discussed, including identifying problem areas and developing recommendations for improvement. These meetings can be formal and informal exchanges of information, test results, drill feedback, and best practices; they can be ship-wide, or can be smaller discussions between department members, crew members assigned a particular task, or similar interested parties.

The process of holding meetings to discuss shipboard life, conditions, practices, and changes to enhance any of these.

The process of providing continuing education and professional development services for crew members. This can include formal high school equivalency, college, and graduate studies aboard ship; self-study programs for safety, management, engineering, or recreational interests; or the provision of tutors, educators, or scholars aboard for specific classes, tasks, or programs.

The process of providing personnel promotion, retention, and career planning services aboard ship. This can include the use of self-study and educational materials aboard, ship; formal and informal conversations between crew members with respect to career planning and personnel retention; and formal programs introduced aboard ship for crew member promotion, retention, and career planning.

11. REGULATORY COMPLIANCE

11.1 Regulatory Compliance

The process of effecting deck pollution prevention regulatory compliance activities, including securing drains, valves, and pumps; insuring that equipment is tagged out and secure; installation of drip pans; and stationing of pollution prevention and clean-up equipment prior to fuel or cargo transfer. This also includes maintaining the safety of deck equipment, systems, and services; monitoring and controlling compliance with safety and environmental protection; developing deck emergency plans and procedures; and controlling deck pollution emergencies.

The process of effecting pollution prevention activities associated with the main propulsion system. This includes maintaining the safety of engineering equipment, systems, and services; monitoring and controlling compliance with safety and environmental protection; developing engineering emergency plans and procedures, and controlling engineering emergencies. This also includes securing drains, valves, and pumps; insuring that equipment is tagged out and secure, installation of drip pans; and stationing of pollution prevention and clean-up equipment prior to fuel or cargo transfer.

The procedures for maintaining current required shipboard certification and documentation.

The process of maintaining a library of government publications and policy manuals.

The process of checking and verifying that crew members are physically prepared for the impending voyage; this includes physical exams crew members must undergo to ensure members are fit to handle shipboard duties, which may include drug and alcohol testing, as required.

The process of checking and verifying that communication equipment, including the Global Marine Distress Safety System (GMDSS), and EPIRB are functional. This also includes diagnostic and verification activities, and standalone and system interface testing.

The process of organizing and conducting workplace safety inspections and fire hazard inspections. This includes training of fire inspectors.

The process of conducting reviews and visual examinations of shipboard spaces so as to ensure their cleanliness. These activities include not only the visual examinations and walk around periods, but follow-up and unscheduled inspections, so as to ensure that all regulations regarding sanitary conditions are met.

The process of planning shipboard reviews and visual examinations of shipboard spaces so as to ensure their cleanliness. Planning activities can include review of safety and sanitary regulations, review of company sanitary, safety, and shipboard regulations, and development of pre- and post-inspection regimes so as to ensure that all regulations regarding safety and sanitary conditions are met.

The process of preparing the vessel, its personnel and facilities for periodic oversight inspections required by safety regulations. This includes meetings and conferences with shoreside management, and coordination of activities in order to insure oversight inspection and safety goals and objectives are met.

12. CARGO RESPONSIBILITIES AND PASSENGER CARE

12.1 Cargo Planning

The process of preparing the plan that details the quantities and description of the various items composing a ship's cargo in order to enable shipboard officers and agents at various ports to make necessary arrangements in advance for the expeditious discharge and loading of the cargo. This includes review of initial cargo assignments, review of the vessel voyage and route, review and development of the vessel transfer plan, and planning and coordination of terminal cargo operations. In addition, this includes development of revisions to and a final cargo/transfer plan, and required stability calculations.

12.2 Cargo Load & Discharge

The process of preparing cargo and cargo spaces for the carriage of cargo, including preparations for cargo load, preparations for cargo discharge, including laying out wires, ropes, shackles, manifolds, and tackle; breaking out cranes, hoists, derricks, and ground tackle; making the vessel ready for receipt/discharge of cargo including preparation; shipboard-terminal communications, including any pre-transfer conferences; safety and cargo equipment preparations; preparations for gas free operations and tank cooling on LNG/LPG vessels.

12.3 Cargo Equipment Test

The process of checking and verifying that cargo and cargo equipment is ready for transfer. This includes review of stowage and transfer plans, policies, and practices; reviews of cargo tests and amounts, inert gas systems, cargo monitoring systems, as well as checking and verifying actual cargo equipment: cranes, hoists, derricks, tackle, shackles, lines, ropes, wires, hoses, valves, pumps, manifolds, blanks, flanges, etc.

12.4 Cargo Loading

The process of loading cargo onto the ship including taking soundings and topping off. This includes loading cargo, including maintaining a cargo watch, stability calculations, checking lines, reading drafts, and ensuring cargo, personnel, and vessel integrity; and securing cargo and safety equipment following cargo loading.

12.5 Cargo Unloading

The process of discharging cargo from the ship. This includes cargo calculations, safety and cargo equipment preparations which includes hold/cargo tank; discharging cargo, including maintaining a cargo watch, stability calculations, checking lines, reading drafts, and ensuring cargo, personnel, and vessel integrity; and securing cargo and safety equipment following cargo discharge.

12.6 Cargo Maintenance

The process of checking, monitoring, and maintaining cargo carried on board, including cargo stability calculations. This includes daily (and more often, if required) checks of cargo carried, taking soundings, monitoring inert gas levels and oxygen, ballasting operations, daily checks of stowage and security arrangements, maintenance of cargo records documenting cargo maintenance, including refrigerated cargo equipment maintenance and inspection, and cargo transfer.

12.7 Cargo Monitoring and Record Keeping

The process of producing, maintaining, and updating records related to the vessel's cargo and its stability calculations. This includes cargo manifests, bills of lading, tonnage certificates, and other marine certificates as required, loading and discharge certificates, gas free certificates, inspection certificates, and cargo, stowage, and load plans.

12.8 Refrigerated Cargo Monitoring and Record Keeping

The process of insuring and documenting that the refrigerated cargo carried is secured, properly stowed, properly chilled or cooled, and handled.

12.9 Hazardous Cargo Monitoring and Record Keeping

The process of ensuring that hazardous cargo is stored and monitored in a safe fashion which includes producing, maintaining, and updating shipboard records of hazardous cargo, particularly documenting where the cargo was loaded, how handled, how protected, where stowed, how often checked, and safety and security precautions effected to insure the safety of the hazardous cargo.

12.10 Tank Cleaning

The process of cleaning cargo tanks. This includes safety preparations and post-cleaning inspections.

12.11 Ballast Maintenance and Soundings

The process of monitoring and controlling the water taken on board in order to maintain the stability of the vessel and trim. This includes daily rounds to determine ballast levels, recording and comparing ballast levels, conducting stability calculations, and transferring ballast as necessary to maintain correct stability levels.

The process of taking on water in order to maintain the stability of the vessel and trim. Ballast loading includes monitoring tank cleaning for loading ballast, stability calculations, reviews of cargo, fuel, and water transfer plans, stability calculations and recalculations, taking soundings, and trimming the vessel so as to enhance vessel performance and fuel economy.

The process of discharging or transferring water in order to maintain the stability of the vessel and trim. Ballast discharge includes stability calculations, reviews of cargo, fuel, and water transfer plans, stability calculations and recalculations, taking soundings, monitoring of overboard discharge for oil pollution prevention, and trimming the vessel so as to enhance vessel performance and fuel economy.

The process of maintaining and calculating the vessel's stability.

12.12 Ballast Discharge or Transfer

The process of discharging or transferring water in order to maintain the stability of the vessel and trim. Ballast discharge includes stability calculations, reviews of cargo, fuel, and water transfer plans, stability calculations and recalculations, taking soundings, monitoring of overboard discharge for oil pollution prevention, and trimming the vessel so as to enhance vessel performance and fuel economy.

12.13 Ballast Maintenance and Soundings

The process of monitoring and controlling the water taken on board in order to maintain the stability of the vessel and trim. This includes daily rounds to determine ballast levels, recording and comparing ballast levels, conducting stability calculations, and transferring ballast as necessary to maintain correct stability levels.

13. HOTEL SERVICES

13.1 Hotel Services Administration

The process of supervising the activities of the steward department. This includes planning a meal schedule, tracking labor expenditures, and reporting the state of the department to the captain.

13.2 Food Preparation, Service, and Galley Cleaning

The process of preparing a salad bar, soups, stocks, sauces, entrees, starches, vegetables, beverages, and deserts for the crew. It includes the drawing of appropriate stores for the preparation of meals.

The process of serving prepared meals to the crew. This includes preparation of tables and mess areas, replenishing self-service stations, and delivery of meals to personnel confined to the bridge.

The process of maintaining a sanitary environment for the preparation and consumption of meals. This includes cleaning of pots, pans, utensils, equipment, dishes, glasses, and silverware.

13.3 Bridge, Accommodation and Space Cleaning

The process of ensuring that accommodations are kept clean and orderly. This includes floor sweeping, washing, and maintenance; window and porthole cleaning; laundry services; linen changing and head cleaning; salt washdowns for the accommodation superstructures; and wipedown of the bridge, all accommodations and living spaces.

13.4 Provisioning and Provisioning Management

The process of ordering, inventorying, and planning galley, cleaning, and shipboard supplies and food so as to ensure adequate and contingency stores for the vessel's voyage.

13.5 Galley Stores and Supplies

The process of receiving, handling, and storing galley stores for the voyage.

13.6 Recreation

The process of insuring adequate recreational opportunities for crew members to pursue during free time. This includes time spent preparing, producing, planning and providing recreational activities as well as time preparing facilities and personnel for recreational activities.

14. ARRIVAL, DEPARTURE AND PORT WATCHKEEPING

14.1 Departure Preparation and Testing

The process of checking and verifying that the vessel and its crew are prepared for the impending departure of the vessel. This includes testing navigational equipment, steering gear, main and auxiliary propulsion equipment, storage of lines, cargo calculations, gauging of tanks, securing bulk cargoes, required drug and alcohol testing for crew members, and safety and cargo systems tests required prior to vessel departure.

14.2 Arrival Preparation and Testing

The process of checking and verifying that the vessel and its crew are prepared for the arrival of the vessel into a port. This includes testing navigational equipment, steering gear, main and auxiliary propulsion equipment, breaking lines out or "warming" winches and anchor windlasses, cleaning anchor, plugging, scrapping, and safety and cargo systems tests required prior to vessel arrival.

14.3 Escort Vessel Interaction/Coordination

The process of ensuring escort vessel interaction is facilitated. This includes tethering and untethering of escort vessels, escort vessel coordination conferences, standing by escort vessel lines, and monitoring escort vessel operations and interactions.

14.4 Docking

The process of assisting a vessel into a dock. This includes guidance of the vessel from just off the pier to the pier, and may or may not include the use of tugs. In addition, docking involves putting down the gangway, breaking out lines or "warming" winches and anchor windlasses, cleaning anchor, plugging, scrapping, securing the vessel to the shore with adequate lines, ropes, wires, etc., checking for vessel security, reading the vessel's draft at appropriate intervals, and insuring that the vessel is adequately lighted.

14.5 Undocking

The process of releasing the vessel from its shoreside securings. This includes guiding the vessel off the pier, and may or may not include the use of tugs. In addition, undocking involves securing the gangway, taking aboard and stowing the vessel's lines, ropes, wires, etc., checking for vessel security, gauging tanks, cargo calculations, securing bulk cargo, reading the vessel's draft if possible, and insuring that the vessel is properly lighted once away.

14.6 Mooring to Buoy

The process of securing a ship in a particular place by means of two or more anchors or cables which are made fast to a wharf, pier, another ship, the shore, or to anchored mooring buoys. This includes guidance of the vessel from just off the pier to the wharf, pier, or another ship; and may or may not include the use of tugs. In addition, mooring involves putting out a brow, gangway, or ladder for external access; breaking out lines or "warming" winches and anchor windlasses, clearing the anchor, plugging, scrapping, securing the vessel with adequate lines, ropes, wires, etc.; checking for vessel security; reading the vessel's draft at appropriate intervals; and insuring that the vessel is adequate lighted. This may also involve establishing a mooring watch and taking mooring bearings to ascertain the ship's position.

14.7 Unmooring from Buoy

The process of pulling in one anchor and casting off mooring lines from a wharf, pier, another ship, the shore, or from anchored mooring buoys. In addition, unmooring involves securing the gangway, brow or ladder used for external access; taking aboard and stowing the vessel's lines, ropes, wires, etc.; checking for vessel security; reading the vessel's draft if possible; and insuring that the vessel is properly lighted once away.

14.8 Anchoring

The process of dropping anchor, thus becoming attached to the ground at sea bed, and so rendered stationary. This includes preparation for anchor let go, clearing the hawse and chocks, checking the anchor brake, insuring that adequate and appropriate lights and day shapes are available to indicate that the vessel is lighted, and making the anchor security fast once anchored, and establishing an anchor watch to ensure that the vessel maintains its anchorage.

14.9 Weighing Anchor

The process of pulling in the anchor. This includes preparation for heaving in, including clearing the hawse and chocks, checking the anchor brake, insuring that adequate and appropriate lights and day shapes are available to indicate that the vessel is anchored, insuring that adequate power is available for heaving in, and making the anchor fast once the anchor is home.

14.10 Crane and Tug Operation

The process of directing and controlling the use of tug boats and floating cranes in support of shipboard work. This may include the use of tugs and cranes in the transfer of cargo between vessels, alongside a pier, from one station to another, or to bring passenger artifacts or shoreside equipment aboard.

14.11 Monitor Vessel's Lines and Security

The process of planning, preparing and insuring that the vessel is secure to its moorings, the pier, a wharf, or another ship. This includes watchkeeping in port, making frequent rounds throughout the vessel to determine her security, logging the results and findings of those rounds, checking the vessel's draft at periodic intervals, checking the security of deck scuppers watertight doors, and monitoring the weather so as to insure adequate vessel security, planning and preparation in the face of impending weather changes.

The process of planning, preparing and insuring that the vessel is secure from the intrusion of those who would do harm to crew members, pilfer cargo, or illegally remove cargo from the vessel while at sea, at anchor, at its berth, or its moorings.

The process of planning, preparing and insuring that the vessel is secure from the intrusion of those who would seek illegal passage aboard the vessel.

15. SPECIAL OPERATIONAL REQUIREMENTS

15.1 Underway Lightering Planning

The process of preparing the plan that details the quantities and description of the various items composing a ship's cargo in order to enable shipboard officers and agents at various ports to make necessary arrangements in advance for the expeditious discharge and loading of the cargo.

15.2 Underway Lightering Loading

The process of loading cargo onto the ship. This includes preparations for cargo load, including paying out wires, ropes, shackles and tackle; breaking out cranes, hoists, derricks, and ground tackle; making the vessel ready for receipt of cargo; shipboard-terminal communications, including any pre-transfer conferences; safety and cargo equipment preparations, and securing cargo and safety equipment following cargo loading.

15.3 Underway Lightering Discharge

The process of unloading cargo from the ship. This includes preparations for cargo discharge, including laying out wires ropes, shackles and tackle; breaking out cranes, hoists, derricks, and ground tackle gauging and cargo calculations; oil record book, making the vessel ready for cargo discharges; shipboard-terminal communications including any pre-discharge or transfer conferences; safety and cargo equipment preparations, and securing cargo and safety equipment following cargo discharge.

15.4 Underway and Vertical Replenishment Operations

The process of taking in cargo while underway, from either shipboard or airborne (vertical replenishment) sources. This includes required planning activities; pre-transfer conferences; replenishment maintenance, planning and preparation operations; personnel assistance with replenishment operations, including securing transfer hoses, security lines and safety watches, as well as disestablishing shipboard and airborne connections and safety watches.

APPENDIX B: Detailed Conceptual Model

Introduction

The purpose of this appendix is to describe the approach and algorithms used in the computer simulation. This description is meant to describe the simulation in sufficient detail so that it can be understood and replicated by model developers.

To describe the computer simulation we have adopted two software engineering formalisms: state transition and data flow diagrams. Each of these is required to document different aspects of the model. Because the simulation is an event-driven dynamic system, the system states and the transitions between these states are defining characteristics of the simulation. State transition diagrams can capture these system characteristics in a rigorous and unambiguous manner. Transitions between system states are often governed by changes in variables and the result of computations (e.g., the calculation of cumulative workhours of crew members). For this reason, data flow diagrams are useful in describing the relationship between variables and the specific data transformations and calculations that must be performed. State transition diagrams can be combined with data flow diagrams to describe the dynamic characteristics and data transformations of the simulation. To document the simulation of shipboard activity thoroughly, this appendix includes four sections that describe:

- State transition diagrams of simulated shipboard activity.
- Data flow diagrams of model algorithms.
- A detailed data dictionary of simulation variables.
- MicroSAINT simulation algorithms.

State Transition Diagrams Of Simulated Shipboard Activity

State transition diagrams are a software engineering tool for documenting the time-dependent system behavior (Yourdon, 1989). These diagrams identify system states and the conditions or events that lead to changes in system states.

Figure 1 shows a state transition diagram that for the simulation of shipboard activities. The rectangles represent system states and the arrows represent conditions or events that trigger transitions from one system state to another. Figure 1 shows that shipboard activity can be described by three sets of systems states and transitions. One set represents the progression of the voyage, another represents the status of the crew members, and the third represents the state of shipboard tasks. Identifying the states and associated transitions defines the range of events and information that must be considered to represent shipboard activity.

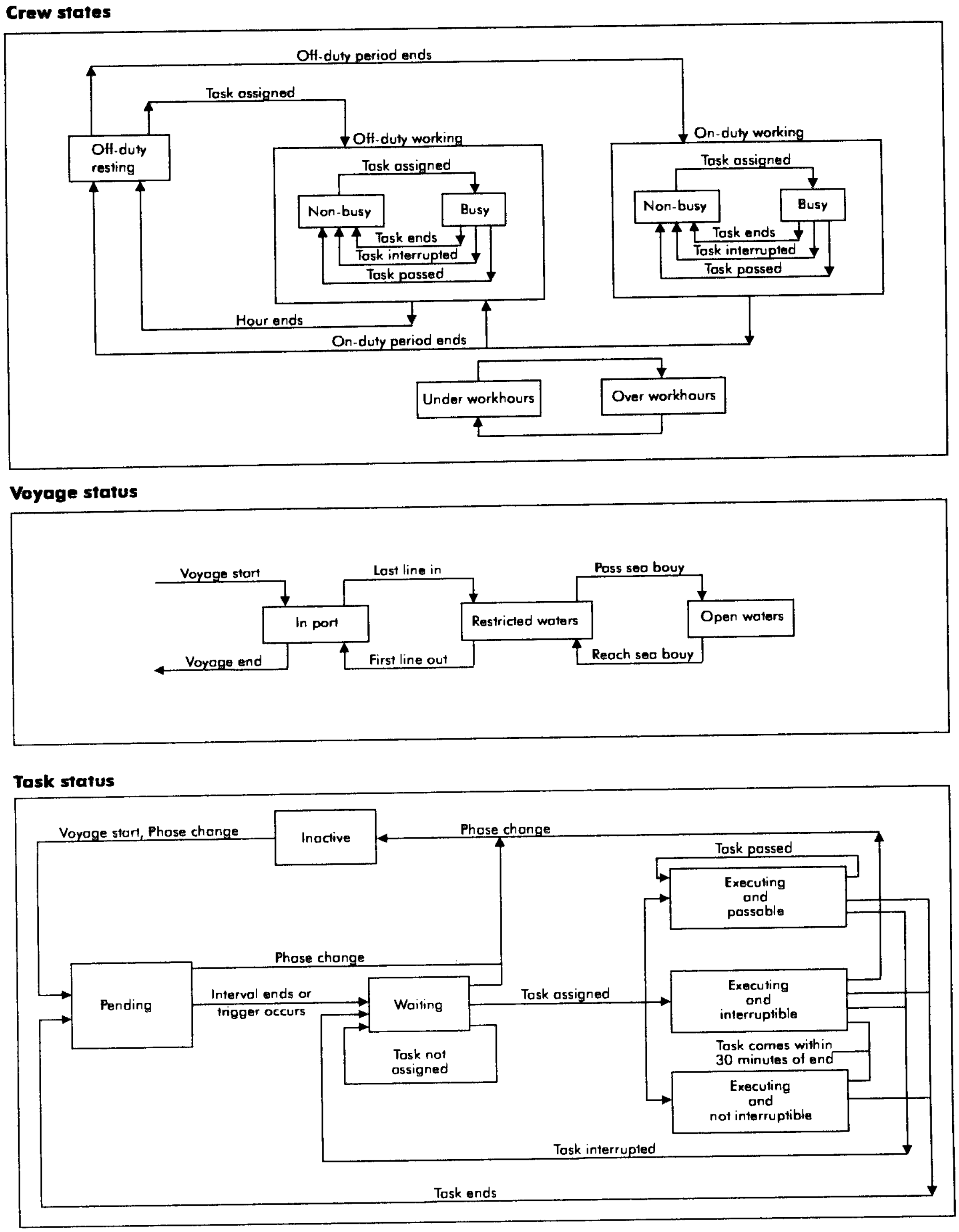

Figure 1. A summary state transition diagram of the overall simulation process.

Data Flow Diagrams of Model Algorithms

Whereas state transition diagrams document the dynamic aspects a system, data flow diagrams document algorithms and data transformations associated with transforming input data into simulation results. Data flow diagrams emphasize the flow of information by describing the system as a network of functions and the information interfaces that link them (DeMarco, 1979). In documenting the simulation of shipboard activity, data flow diagrams identify the required functions, transformations, and calculations and the associated data needs.

Figure 2 shows a data flow diagram of the basic simulation elements and Figures 3, 4, and 5 show the more detailed processes associated with each of the three primary processes. In this way, Figure 2 indicates the relationship among the more detailed processes. The ovals in these figures represent data transformations or processes, the arrows represent information flows and the boxes represent data sources or sinks outside the system. Thus, the same conventions are used to describe the summary information shown in Figure 2 and the detailed information shown in Figures 3, 4, and 5.

Figure 2 includes three ovals, representing the three primary processes of the simulation and three major inputs or information sources. These information sources are shown as boxes with arrows leading from them to the processes. The figure also shows two outputs or information sinks. These are also shown as boxes with arrows leading to them from the processes. The arrows show the information that is used as input, the information flows between processes, and the information that is produced by the simulation. The three primary processes address the data transformations and calculations associated with the progression of the voyage, the occurrence of tasks, and the crew member activities.

Figures 3, 4, and 5 provide a more detailed view of each of the three main processes. Each of these figures shows the detailed functions that must be performed by the simulation. In each of these figures, the arrows are annotated to show the data that are passed from one process to another. These annotations are variable names, which are defined in detail in the data dictionary.

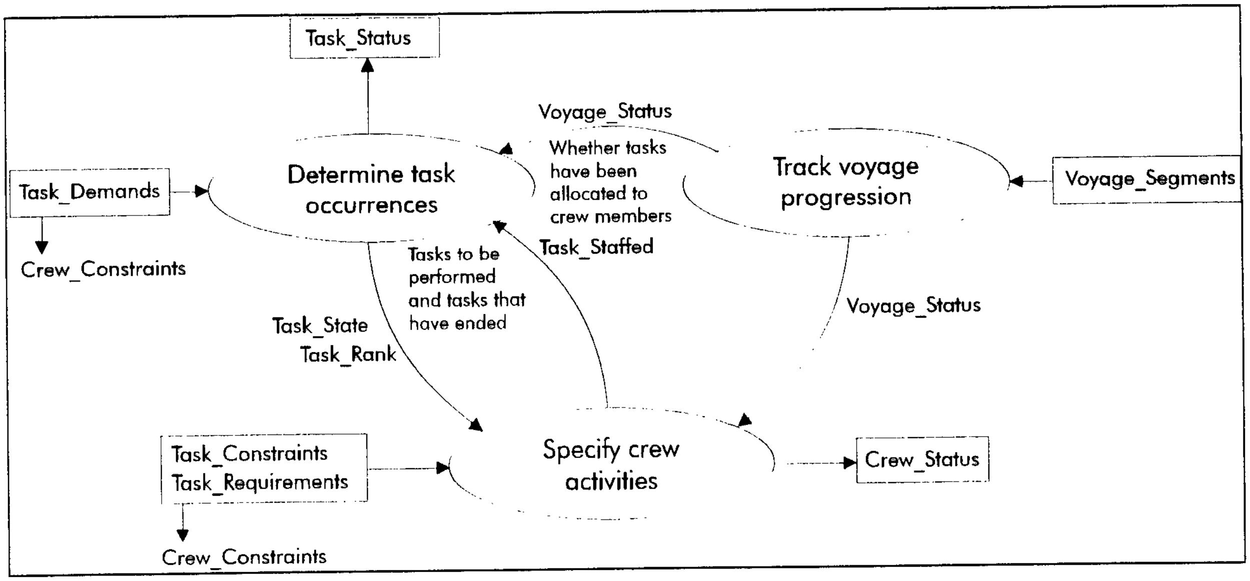

Figure 2. A data flow diagram of the basic simulation elements.

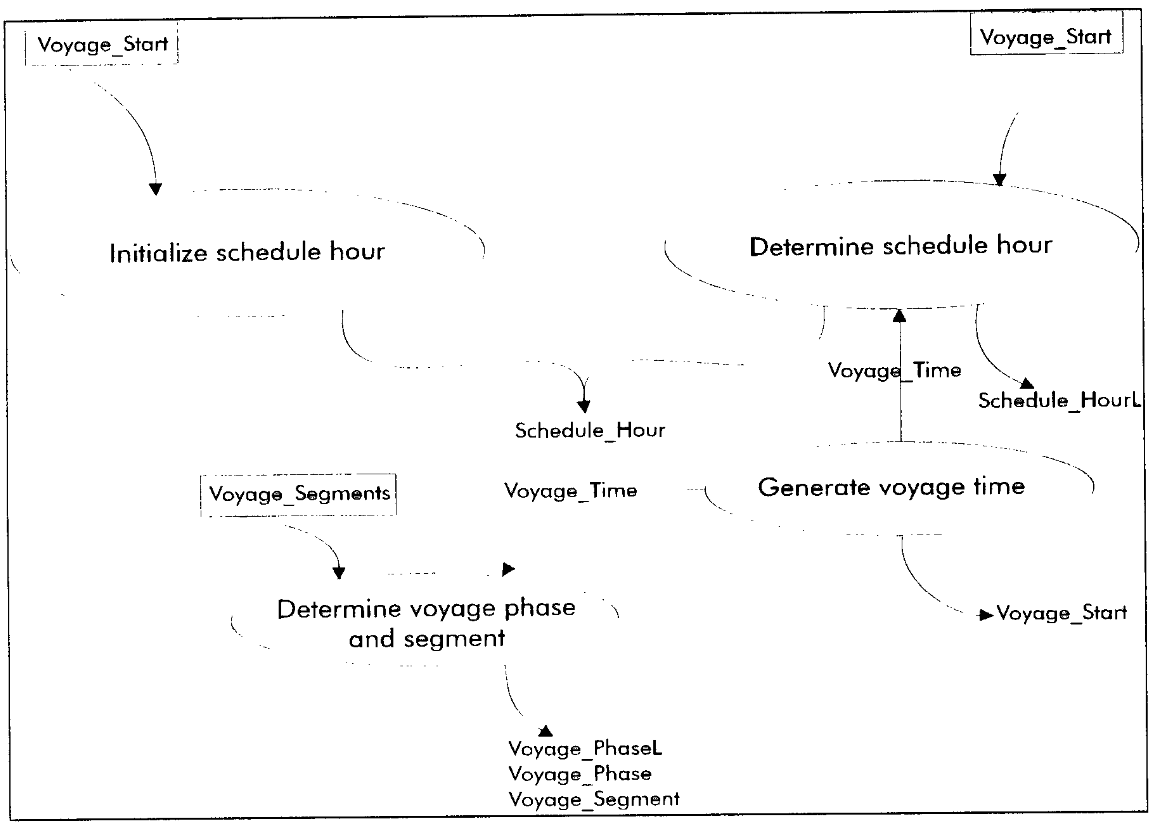

Figure 3. A detailed data flow diagram showing the processes for "Track voyage progression."

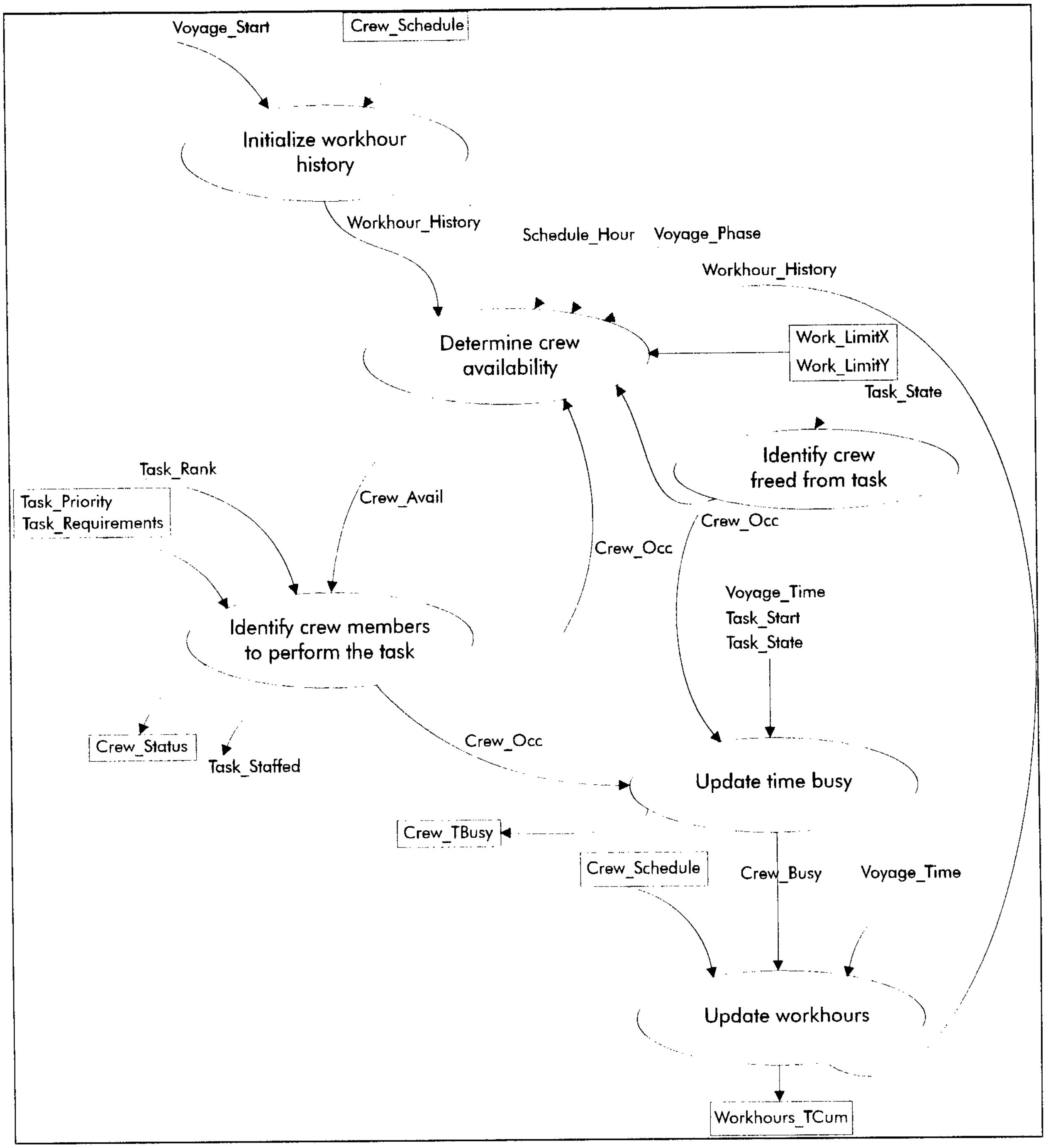

Figure 4. A detailed data flow diagram showing the processes for "Specify crew activities."

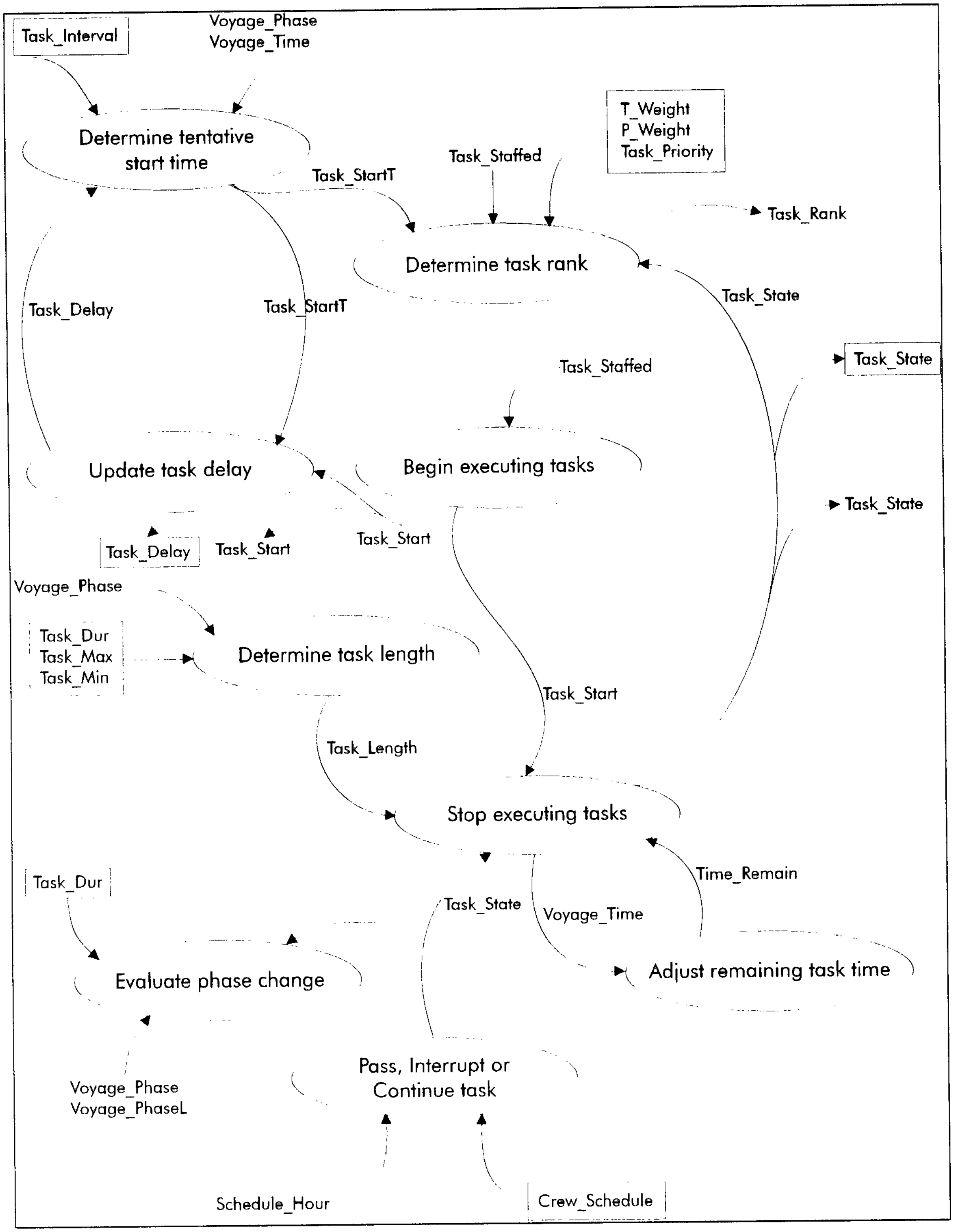

Figure 5. A detailed data flow diagram showing the processes for "Determine task occurrences."

A DETAILED DATA DICTIONARY OF SIMULATION VARIABLES

The data flow diagrams identify data and transformations, processes, and calculations (functions) performed with the data. To avoid ambiguity, the data dictionary defines each of the data elements. To define the data elements, we have adopted several of the data definition conventions outlined in Demarco (1979). Specifically, the data dictionary follows the top-down partitioning of the simulation reflected in the data flow diagrams. This top-down process generates general data elements that are composed of subordinate elements, which may also consist of further subordinate elements. To describe these hierarchical relationships, the data dictionary shows names of data elements as a combination of all the subelements of which it is composed. For example, the data element describing the ship route and voyage characteristics, Voyage_Profile, is composed of several subelements, and so its definition is shown as Voyage_Profile = Voyage_Segment + Voyage_Status. In this case = means "equivalent to" and + means "and." This hierarchical description of the data elements provides the context for understanding the meaning of the subordinate data elements by showing how they relate to the high-level data elements describing the simulation.

Because many of the data names exceed the character limit for MicroSAINT variables, many data elements have a MicroSAINT alias. This alias is shown as part the data definition, along with the size and type of the data storage allocated to the data element.

Data Dictionary for the Crew Size Evaluation Model

Task_List = Task_Identification + Task_Demands + Task_Requirements + Task_Constraints + Task_Status

Task_Identification =	Task_ID + Task_N
Task_ID	Unique identifier of each task. MicroSAINT alias = tag, task.
Task_N	Total number of unique tasks, duplication due to voyage phase does not result in additional tasks.

Task_Demands =	Task_Dur + Task_Min +Task_Max+Task_Period + Task_Frequency + Task_Interval
Task_Dur	Average length of a task from beginning to end with no interruptions, in minutes. Matrix (Task_N_X Phase_N). MicroSAINT alias = T_Dur.
Task_Min	The lower bound of the task durations, in minutes. Matrix (Task_N X Phase_N). MicroSAINT alias = T_Min.
Task_Max	The upper bound of the task durations, in minutes. Matrix (Task_N X Phase_N). MicroSAINT alias = T_Max.
Task_Period	The period over which the task repeats.
Task_Frequency	The number of times the task repeats during the Task_Period.
Task_Interval	The time between when a task ends and the time it is scheduled to begin again, in minutes. Matrix (Task_N x Segment_N). MicroSAINT alias = T_Int. (T_Int = Task_Period / Task_Frequency) - Task_Dur).

Task_Requirements =	Task_Pool1, 2, 3, 4, 5 +Task_PoolID +Task_PoolN + Task_CrewN + Task_Watch
Task_Pool1, 2, 3, 4, 5	Pools of potential crew types. Matrix (Task_N X Voyage_PhaseN X Crew_TypeN). MicroSAINT alias = T_Pool1, 2, 3, 4, 5.
Task_PoolID	Differentiates the pools of crew members. MicroSAINT alias Task_PoolID.
Task_PoolN	Number of pools of potential crew members for each task. Matrix (Task_N X Phase_N). MicroSAINT alias = T_PoolN.
Task_PO	The crew pool in which each person is a member. List (Crew_N). MicroSAINT alias = T_PO.
Task_CrewN	The number of crew members required from each pool. Matrix (Task_N X Phase_N X Task_PoolN). MicroSAINT alias = T_CrewN.
Task_Watch	Distinguishes between tasks that are: 1) a required aspect of watchstanding, 2) those that are an optional part of watchstanding, 3) and those that are not part of a watch. Matrix (Task_N X Voyage_PhaseN). MicroSAINT alias = T_Watch.

Task_Constraints =Task_Trigger + Task_Priority + Task_Passable + Task_Interrupt	
Task_Trigger	Events, or Phase changes that trigger task occurrence. Matrix (Task_N X Voyage_PhaseN). MicroSAINT alias = T_Trig.
Task_Priority	Relative priority of tasks, either low, medium, or high. 1=low, 2=medium, 3=high. Matrix (Task_N X Voyage_PhaseN). MicroSAINT alias = T_Priority.
Task_Passable	Whether the task can be passed to another crew member to complete. Matrix(Task_N X Voyage_PhaseN). 1=yes, 0=no. MicroSAINT alias = T_Pass.
Task_Interrupt	Whether the task can be interrupted while it is being performed. Matrix(Task_N X Voyage_PhaseN). 1=yes, 0=no. MicroSAINT alias = T_Intrupt.

Task_Status =	Task_Pending + Task_Waiting + Task_Executing + Task_Inted + Task_ExecutingN + Task_Sat + Task_Staffed + Task_Rank + P_Weight + T_Weight + Task_Delay + Task_Length + Task_Remain + Task_Start + Task_StartT + Task_State
Task_Eval	The total tasks evaluated for crew assignment. MicroSAINT alias = T_Eval.
Task_Pending	Task is waiting for the interval between task occurrences to end. List (Task_N) 1=yes, 0=no. MicroSAINT alias = T_Pend.
Task_Waiting	Task is waiting for available crew members to be assigned. List (Task_N) 1=yes, 0=no. MicroSAINT alias = T_Wait.

Task_Executing	Task is actively being performed or not. List (Task_N) 1=yes, 0=no. MicroSAINT alias = T_Exe.
Task_Passed	Whether or not a task has been passed. List (Task_N). MicroSAINT alias = T_Passed.
Task_Inted	Tasks that have been interrupted. List (Task_N) 1 = yes, 0 = no. MicroSAINT alias = T_Inted.
Inted_Task	Tasks interrupted keyed by number of tasks interrupted. List(Task_N). MicroSAINT alias = Inted_T.
Task_IntedN	The number of tasks interrupted. MicroSAINT alias = T_IntedN.
Task_Active	Number of tasks currently being performed. MicroSAINT alias = T_Active.
Task_ExecutingN	Number of tasks currently being performed/executing. Integer, range 1 - Task_N. MicroSAINT alias = T_ExeN.
Task_WaitingN	Tracks tasks waiting to be performed. MicroSAINT alias = T_WaitingN.
Task_FExe	The tasks which will be executed in the future. List (Task_N). MicroSAINT alias = T_FExe.
Task_FActive	Whether or not a future task is active. List (Task_N). MicroSAINT alias = T_FActive.
Task_Sat	Number of crew allocated to satisfy the crew requirements of each task. Matrix (Task_N X Pool_N). 1-Task_CrewN. MicroSAINT alias = T_Sat.
Task_Staffed	Sufficient crew are available to meet the requirements of all crew pools associated with the task. List (Task_N). MicroSAINT alias = T_Staffed.
Task_Rank	Combination of Task_Priority and Task_StartA (approximate task start time) used to determine the order in which tasks are assigned crew members. List (Task_N). MicroSAINT alias = T_Rank.
P_Weight	Weights task priority when calculating task rank.
T_Weight	Weights task start time when calculating task rank.
Task_Delay	Time between when the task was scheduled to begin and the current time. Any delay is due to lack of appropriate crew in minutes. List (Task_N). MicroSAINT alias = T_Delay.
Task_Length	The actual duration of the task. This will differ from Task_Dur only when variations in task duration are considered, such as in the stochastic analysis. List (TaskN), in minutes. MicroSAINT alias = T_Length.
Task_AssignT	The time tasks have last been assigned. MicroSAINT alias = T_AssignT.
Task_Remain	The time required to finish a task. This is equal to the Task_Length when the task begins and is equal to zero when the task ends. List (TaskN), in minutes. MicroSAINT alias = T_Remain.
Task_Time	The time the task was performed. List (Task_N). MicroSAINT alias = T_Time.
Task_Start	The time a task begins. List (Task_N). MicroSAINT alias = T_Start.
Task_StartT	The approximate start time of each task. List (Task_N). MicroSAINT alias = T_StartT.
Work_Start	The time when a watchstanding task should start. MicroSAINT alias = W_Start.
Task_State	Describes the current state of the task. 1 = beginning, 2 = finishing, 3 = interrupted, 4 = passed to other crew, 5 = continued with same crew. List (Task_N). MicroSAINT alias = T_State.

Crew_Complement = Crew_Description + Crew_Constraints + Crew_Status

Crew_Description =	Crew_ID + Crew_N
Crew_ID	Numeric identifier of each crew member that uniquely identifies crew member as an individual. Integer, range 1-Crew_N. MicroSAINT alias = crew
Crew_N	Total number of crew associated with the ship. Integer, range 1-35.

Crew_Constraints =	Crew_Pos + Crew_Type + Crew_TypeN + Crew_Comp
Crew_Pos	Position of each crew member. 0=Dayworker, 1=Watchstander. MicroSAINT alias = C_Pos.
Crew_Type	The position that each crew member occupies. Each crew member is identified by only one type. List (Crew_N). Integer coded to crew type. MicroSAINT alias = C_Type.
Crew_Watch	Whether a crew member is a watchstander or a dayworker. MicroSAINT alias =

	C_Watch.
Crew_TypeN	Number of crew types. Max 50. MicroSAINT alias = C_TypeN.
Crew_Comp	The crew complement, the number of crew members of each crew type. List (Crew_TypeN). MicroSAINT alias = C_Comp.
Crew_Away	Whether or not a crew member is on-board and able to work. If a crew member is away, he cannot be assigned to a task. 1 = Away, 0 = Present. MicroSAINT alias = C_Away.
Crew_Status =	Crew_Schedule + Work_LimitX + Work_LimitY + Work_LimitN + Workhours_History+ Workhours_Cum + Workhours_TCum + Crew_Over + Crew_Occ + Crew_OccT + Crew_OccN + Crew_Avail + Crew_Busy + Crew_TBusy + Crew_Status
Crew_Schedule	Hours an individual crew member is on-duty. For each crew position by hour. Can be specified by Crew_Watch and Watch_Start or by customization. Matrix (Crew_N X Phase X 48) = yes/no. MicroSAINT alias = C_Sched.
Work_LimitX	Number of hours during a particular period crew positions are able to work. Matrix (Crew_TypeN X Limit_N) = integer, range = 0 - Work_LimitY, in hours. MicroSAINT alias = W_Limit X.
Work_LimitY	Number of hours over which work hours are calculated (.e.g., X hours in Y hours) Matrix (Crew_TypeN X Limit_N) = integer, range = 1 - 72, in hours. MicroSAINT alias = W_LimitY.
Work_LimitN	The number of limit periods. Currently OPA90 has 2, 24 hr and 36 hr. Range 1-4. List(Crew_TypeN). MicroSAINT alias = W_LimitN.
Workhours_History	The time worked in each of the 72 hours preceding the current voyage time. Matrix (Crew_N X 72). MicroSAINT alias = W_His.
Work_HisF	The time worked in each of the 72 hours preceding the current voyage time. Matrix (Crew_N X 90). MicroSAINT alias = W_HisF.
Workhours_Cum	The cumulative workhours for the period of the workhour limit (Work_LimitY). Matrix (Crew_N, Work_LimitN) = integer, range = 0- Work_LimitY, in minutes.
MicroSAINT	alias = W_Cum.
Work_CumF	The cumulative work hours for the period of the workhour limit (Work_LimitY). Matrix (Crew_N, Work_LimitN). MicroSAINT alias = W_CumF.
Workhours_TCum	The total number of minutes a crew member has worked or been on-duty from the start of the voyage. List (Crew_N). MicroSAINT alias = W_TCum.
Crew_Over	Whether or not a crew member is over workhour limits. List (Crew_N). 1 = over limit, 0 = within limit. MicroSAINT alias = C_Over.
Crew_Occ	Task currently occupying each crew member. List (Crew_N) = 0 if unoccupied, otherwise it is the task number. MicroSAINT alias = C_O.
Crew_OccL	The last task to occupy each crew member. List (Crew_N).
Crew_OccT	Temporary assignment of crew member to a task. List (Crew_N) = 0 if unoccupied, otherwise it is the task number. MicroSAINT alias = C_OT.
Crew_OccN	Total number of crew actively performing a task. List (1-Voyage_Time) = integer, max<CrewN. MicroSAINT alias = C_ON.
Crew_Avail	Level of crew availability. List (Crew_N), range 1-10. MicroSAINT alias = C_Avail.
Crew_AvailN	Whether or not crew are at each available level. List (Levels of availability). MicroSAINT alias = C_AvailN.
Crew_AvailW	Tracks crew availability for watchstanding tasks. List (Crew_N). MicroSAINT alias = C_AvailW.
Crew_Alloc	The number of crew members who have been allocated. List (Crew_N). MicroSAINT alias = C_Alloc.
Crew_Busy	Calculates time spent occupied with tasks in each hour. List(Crew_N). MicroSAINT alias = C_Busy.
Crew_BusyN	The number of crew members busy working on all tasks at any time. MicroSAINT alias = C_BusyN.
Crew_TBusy	Calculates total cumulative time spent occupied with tasks. MicroSAINT alias = bu.
Crew_Status	Identifies the status of each crew member. -1 = leaving the task, 1 = starting the task. List (Crew_N). MicroSAINT alias = c.
Crew_OP	Percentage of capability devoted to task. List (Crew_N). MicroSAINT

alias = C_OP.

Crew_OPL	Percentage of capability occupied on previous task. List (Crew_N). MicroSAINT alias = C_OPL.
Crew_OPF	Percentage of crew members used on task. List(CrewN). MicroSAINT alias = C_OPF.
Crew_OW	The number of crew members occupied with watch duties. List (Crew_N). MicroSAINT alias = C_OW.
Crew_OWL	Last watch duty occupying crew member. List (Crew_N). MicroSAINT alias = C_OWL.

Crew_AlSleep = Crew_Alert + Crew_AlertC + Crew_AlertL + Crew_AlertM + Crew_AlertP + Crew_AlertS + Crew_AlertSp + Crew_AlertU + Crew_Send + Crew_Slcum + Crew_SlCum + Crew_Slcum + Crew_Sleep + Crew_SleepL + Crew_SlendT + Crew_SlstartT + Crew_Sstart

Crew_Alert	Tracks alertness level of crew. List (Crew_N). MicroSAINT alias = C_Alert.
Crew_AlertC	Circadian component of alertness. MicroSAINT alias = C_AlertC.
Crew_AlertL	Parameter for alertness calculation. MicroSAINT alias = C_AlertL.
Crew_AlertM	Parameter for alertness calculation. MicroSAINT alias = C_AlertM.
Crew_AlertP	Phase shift of circadian rhythm in 24-hour clock. MicroSAINT alias = C_AlertP.
Crew_AlertS	Tracks the homeostatic component of alertness. List (Crew_N). MicroSAINT alias = C_AlertS.
Crew_AlertSp	Tracks the homeostatic component during sleep. List (Crew_N). MicroSAINT alias = C_AlertSp.
Crew_AlertU	Parameter for alertness calculation. MicroSAINT alias = C_AlertU.
Crew_Send	Identifies the alertness at the end of sleep. List (Crew_N). MicroSAINT alias = C_Send.
Crew_SlCum	Tracks cumulative sleep in the past 24 hours. List (Crew_N). MicroSAINT alias = C_SlCum.
Crew_Slcum	Cumulative sleep in period. List (Crew_N). MicroSAINT alias = C_SlCum.
Crew_Sleep	The amount of sleep in the current hour. List (Crew_N). MicroSAINT alias = C_Sleep.
Crew_SleepL	The number of hours slept in the last hour. List (Crew_N). MicroSAINT alias = C_SleepL.
Crew_SlendT	The end time of the sleep period for the crew. List (Crew_N). MicroSAINT alias = C_SlendT.
Crew_SlstartT	The start time of the sleep period for the crew. List (Crew_N). MicroSAINT alias = C_SlstartT.
Crew_Sstart	Value of S when sleep starts. List (Crew_N). MicroSAINT alias = C_Sstart.

Voyage_Profile = Voyage_Segments + Voyage_Status

Voyage_Status = Voyage_Length + Voyage_Time + Schedule_Hour

Time	The time of day. MicroSAINT alias = Time.
Schedule_Hour	The hour of the 48-hour shift schedule. 1-48 corresponding to the two-day shift schedule (Crew_Schedule). In hours. MicroSAINT alias = S_Hour.
Voyage_Length	Total time specified for the voyage. MicroSAINT alias = V_Length.
Voyage_Time	Time elapsed from voyage start. MicroSAINT alias = V_Time.
Voyage_Preview	Defines how far into the future, in minutes, voyage segments and work are calculated. MicroSAINT alias = V_Preview.
Voyage_Start	The time of day of the voyage start (00-23). Equal to the time of day of the start of the first segment. MicroSAINT alias = V_Start.
Voyage_End	The time of day of voyage start (0000-2300). Equal to the time of day at the end of the last segment. MicroSAINT alias = V_End.
Voyage_Phase	Describes distinctly different operating conditions and identifies different tasks, task demands and watch structures. List (1-Voyage_PhaseN) 1=In port, 2=Restricted waters, 3=Open waters. MicroSAINT alias = V_Phase.

Voyage_PhaseN	The number of phases in a voyage. Integer, range = 1-6. MicroSAINT alias = V_PhaseN.
Voyage_Segment	The current segment of the voyage. MicroSAINT alias = V_Segment.
Schedule_HourF	The hour corresponding to the schedule. MicroSAINT alias = S_HourF.
Schedule_HourL	The previous schedule hour. MicroSAINT alias = S_HourL.
Voyage_Hour	The current voyage hour. MicroSAINT alias = V_Hour.
Phase_ChangeT	Time of the phase change in voyage minutes. MicroSAINT alias P_ChangeT.
Voyage_PhaseF	The voyage phase Voyage_Preview minutes into the future. MicroSAINT alias = V_PhaseF.
Voyage_PhaseLF	The voyage phase previous to the one Voyage_Preview minutes in he future. MicroSAINT alias = V_PhaseLF.
Voyage_PhaseS	The voyage phase associated with each voyage segment. List V_SegmentN). MicroSAINT alias = V_PhaseS.
Voyage_SegmentF	The voyage segment Voyage_Preview minutes into the future. MicroSAINT alias = V_SegmentF.
Voyage_SegmentN	The total number of voyage segments. MicroSAINT alias = V_SegmentN.
Voyage_SegTime	The start time of each voyage segment. MicroSAINT alias = V_SegTime.

Model Input

Task list

T_Dur (Task_ID, Voyage_Phase) = duration in minutes
T_Min (Task_ID, Voyage_Phase) = duration in minutes
T_Max (Task_ID, Voyage_Phase) = duration in minutes
T_Int (Task_ID, Segment_ID) = interval length in minutes, 100,000 if triggered event
T_Trig (Task_ID, Instance) = approximate time of occurrence in minutes
T_Pass (Task_ID, Voyage_Phase) = 0 = not passable, 1 = interruptible
T_Inrupt (Task_ID, Voyage_Phase) = 0 = not interruptible, 1 = interruptible
T_CrewN (Task_ID, Voyage_Phase, Pool_ID) = number of crew needed from each pod, 100 = 1 person
T_Priority (Task_ID, Voyage_Phase) = 1 = low, 2 = medium, 3 = high
T_PoolN (Task_ID, Voyage_Phase) = number of pools used for task
T_Pool1 (Task_ID, Voyage_Phase, Crew_Type) = 0 if can not be used, 1 if can be used in pool 1.
Task_Pool2 (Task_ID, Voyage_Phase, Crew_Type) = 0 if can not be used, 1 if can be used in pool 2.
Task_Pool3 (Task_ID, Voyage_Phase, Crew_Type) = 0 if can not be used, 1 if can be used in pool 3.
Task_Pool4 (Task_ID, Voyage_Phase, Crew_Type) = 0 if can not be used, 1 if can be used in pool 4.
Task_Pool5 (Task_ID, Voyage_Phase, Crew_Type) = 0 if can not be used, 1 if can be used in pool 5.
T_Watch (Task_ID, Voyage_Phase) = 1 = non-watch, 2 = watch optional, 3 = watch required
Task_N = Total number of tasks

Crew

Crew_N = Number of crew member in crew.
C_TypeN = Number of crew types
C_Comp (Crew_Type) = number of crew in each position
C_Watch (Crew_ID) 0 = Dayworker, 1=Watchstander
C_Type (Crew_ID) = the crew type of each person on the ship
Work_LimitX (Crew_Type, Work_Limit ID) = Workhour_Limits, The maximum number of workhours number of workhours in hours
Work_LimitY (Crew_Type, Work_Limit ID) = Limit_Period, The period of hours over which work hours are calculated in hours
Work_LimitN (Crew_Type) = Number of workhour limits for each crew type
C_Sched (Crew_ID, Voyage_Phase, Scheduled Hour) = 0 if not on duty, 1 if on duty
C_Away (Crew_ID, Voyage_Phase) = 1 if not scheduled, 0 = if scheduled

Voyage profile

Voyage_Start = Starttime of the voyage in hours of real time rounded to the lower hour
Simulation events at the time of each phase change
Voyage_Phase
Voyage_PhaseL
Voyage_Segment = Segment numbered, sequentially from the beginning of the voyage starting with 1
Function call to PHASE_CHANGE

Model Output

Task history

Voyage_Time, Voyage_Phase, Task_ID, T_State, Crew_Active

One line generated at the start, end, interruption, or passage of each task. T_State = 1, if task is starting. T_State = 2, if task is ending, T_State = 3, if task has been interrupted, T_State = 4, if task has been passed. Crew_Active identifies crew that were involved in the task with a 1 if they are beginning to work on a task, -1, if they have finished working on a task, and 0, if they are not involved.

Workhour totals

Work_Cum (Voyage_Time, Crew_ID) = total number of hours have been working during the voyage.

Busy_Cum (Voyage_Time, Crew_ID) total number of minutes crew have been busy performing tasks over the voyage.

One line generated at the end of each hour.

MicroSAINT Functions

ALLOC

Called at end of pending and waiting events. Allocates tasks to crew members. Uses the following variables: T_Sat, T_Staffed, T_Priority, V_Phase, C_AvailN, Crew_N, C_Avail, C_AvailW, T_Int, V_Segment, C_Away, T_PoolN, TPool1, C_Type, C_OW, C_O, T_Watch, C_Alloc, C_Sched, S_Hour, T_PO, T_Remain, T_Start, T_Inted, C_OL, C_OPL, C_OP, T_CrewN, T_Pool2, T_Pool3, T_Pool4, T_Pool5.

TASKSTAFFED
UNASSIGN
UNTEMP
INTERRUPT

ASSIGN

Called at end of pending and waiting events. Initializes variables at the beginning of the crew allocation process, using T_Eval, Crew_N, C_Alloc, T_Waiting, N_Waiting.

CREWOVER

Called by UPDATEAVAIL. Identifies crew members who have exceeded workhour limits, using the following variables: W_Cum, Work_LimitX, C_Type, C_Over, W_CumF.

DEALLOC

Called by TASKEND. Removes crew members from tasks after they have been completed or interrupted, using the following variables: Crew_N, C_O, C_Busy, C_OP, T_Time, C_OL, C_OPL, C_OW, C_OWL.

FALLOC

Called at end of future pending and waiting events. Allocates tasks to crew members, using: T_Sat, T_Staffed, Crew_N, C_OPF, C_Away, V_PhaseF, T_CrewN, T_PoolN, TPool1, C_Type, T_Dur, V_Hour, W_HisF.

INITIATE

Called at the beginning of the simulation. Initiates tasks and begins simulation of voyage segments. Using the following variables: T_Dur, V_Phase, T_Priority.

INITWK

Called at the beginning of the simulation. Initializes workhour histories of each crew member. Using the following variables: Crew_N, Work_LimitN, C_Type, S_Hour, Voyage_Start, C_Sched, W_His, Work_LimitY, W_Cum.

INTERRUPT
Called by ALLOC. Interrupts tasks to free crew members for higher priority tasks. Using the following variables: T_Inted, C_O, T_IntedN, Inted_T.
INTERVAL
Called before each task begins pending. Calculates the interval that must elapse before the task can begin waiting for crew to be assigned. Using the following variable: T_StartT.
INTERVALF
Called before future tasks begin pending. Calculates the interval that must elapse before the task can begin waiting for crew to be assigned. Using the following variables: T_Int, V_Segment, T_Dur.
INTTASKS
Called at the end of each voyage segment and after crew have been assigned to a task. Interrupts tasks that do not occur on a particular phase or that must be interrupted to free crew members for other tasks. Using the following variables: T_IntedN, Inted_T, T_Exe.
PHASECHNG
Called when the voyage segment ends. Initializes begins and tasks that depend on transitions between voyage phases, such as port to restricted waters. Uses the following variables: P_ChangeT, Task_N, T_IntedN, T_Exe, T_Intrupt, V_Phase, T_Remain, T_Start, T_Dur, Inted_T.

INTTASKS

PHASECHNGF
Called when the future voyage segment ends. Initializes begins and tasks that depend on transitions between voyage phases, such as port to restricted waters. Uses the following variables: Task_N, T_Dur, V_PhaseF, T_Priority, T_FActive.
RANK
Called at end of pending and waiting events. Ranks tasks for crew to be assigned. Uses the following variables: T_Rank, P_Weight, T_Priority, V_Phase, T_Weight, T_Start, T_Int, V_Segment.
RESETBUSY
Called at the end of each hour. Resets the time spent busy on a task for each crew member. Uses the following variables: Crew_N, C_Busy.
SCHEDULEHOUR
Called at the end of each hour. Resets the time spent busy on a task for each crew member. Uses the following variables: S_Hour, V_Hour, Voyage_Start, S_HourL, S_HourF.
STARTTIME
Called before each task begins pending. Calculates the tentative start time for each task. Uses the following variables: P_ChangeT, T_Dur, V_PhaseL, V_Phase, T_StartT, T_Int, V_Segment, T_Delay.
STOPTASK
Called at the end of each hour. Identifies and stops tasks. Uses the following variables: Task_N, T_Intrupt, V_Phase, T_Exe, T_Remain, T_Start, Crew_N, C_O, C_Over, C_Sched, S_Hour, T_Dur, T_Inted, T_IntedN, Inted_T.
STOREC
Called by TASKBEGIN and TASKEND. Stores task data describing the crew members who work on each task, and whether the task is beginning or ending. Uses the following variable: Crew_N.
TASKBEGIN
Called at the beginning of each task. Initializes variables and stores data at the start of each task. Uses the following variables: T_Active, T_Exe, T_Start, T_Delay, T_StartT, T_State, T_Remain.

UPDATEC

TASKEND
Called at the end of each task. Initializes variables and stores data at the start of each task. Uses the following variables: T_Exe, T_Active, T_Inted, T_Start, T_Remain, T_StartT, T_Time, T_State, T_Dur, V_Phase.

DEALLOC
UPDATEAVAIL
UPDATEC
UPDATEBUSY

TASKLENGTH
Called at the beginning of each task. Calculates the length of time each task will take to complete. Uses the following variables: T_Delay, T_Min, V_Phase, T_Dur, T_Max, T_Remain.
TASKSTAFFED
Called from ALLOC. Identifies if sufficient crew have been assigned to the tasks. Using the following variables: T_Sat, T_CrewN, V_Phase.
TASKTIME
Determines how long a task will take to complete. Uses the following variable: T_Remain.
UNASSIGN
Called from ALLOC. Removes crew from temporary assignment if sufficient crew members are not available. Using the following

variables: T_Inted, C_OL, Inted_T, T_Int, V_Segment, C_OW, C_OWL, C_OP, C_OPL.

UNTEMP

Called from ALLOC. Makes temporary assignment of crew to tasks permanent so that tasks can begin, using: C_Alloc, C_Avail, C_AvailW.

UPDATEALERTS

Called from UPDATESLEEP. Updates the sleeping component of crew member alertness. Uses the following variables: C_AlertC, C_AlertM, S_Hour, C_Alertp, C_AlertSp, C_AlertU, C_Sstart, V_Hour, C_SlstartT, C_Alert.

UPDATEALERTW

Called from UPDATESLEEP. Updates the waking component of crew member alertness. Uses the following variables: C_AlertC, C_AlertM, S_Hour, C_Alertp, C_AlertS, C_AlertL, C_Send, V_Hour, C_SlendT, C_Alert, C_AlertC, C_AlertS.

UPDATEAVAIL

Called at the end of each hour and by TASKEND. Updates the availability of each crew member for performing a task. Uses the following variables: C_AvailN, Crew_N, C_Avail, C_AvailW, C_Over, C_Sched, V_Phase, S_Hour, C_OP, C_Busy, T_Intrupt, T_Priority, C_OW.

CREWOVER

UPDATEBUSY

Called at the end of each hour and by TASKEND. Updates the time spent working on tasks during the last hour for each crew member. Uses the following variables: Crew_N, C_Busy, C_OPL, T_Start, C_OL.

UPDATEC

Called by TASKBEGIN and TASKEND. Updates the status of the crew members, indicating those that have begun performing a task and those who have finished performing a task. Uses the following variables: C_O, C_OW, C_OWL.

UPDATEREM

Called at the end of each hour. Updates the time remaining to complete a task. Uses the following variables: Task_N, T_Exe, T_Remain, T_Start, T_StartT.

UPDATESLEEP

Called by UPDATEWK. Updates the time spend sleeping by each crew member. Uses the following variables: C_SleepL, C_Sleep, C_Sched, V_Phase, S_Hour, C_OW, C_Busy, C_SlstartT, V_Hour, C_Slcum, C_SlendT, C_Alertsp, C_Sstart.

UPDATEALERTS
UPDATEALERTW

UPDATETIME

Called at the end of each hour. Updates time the time spent working and sleeping for each crew member. Uses the following variables:

UPDATEWK
UPDATESLEEP
UPDATEALERTS
UPDATEALERTW

UPDATEWK

Called by UPDATETIME. Updates the time spent working and sleeping. Uses the following variables: C_BusyN, Crew_N, C_O, C_Busy, C_OP, T_Start, C_Sched, V_Phase, S_Hour, C_OW, W_His, Work_LimitN, C_Type, V_Hour, WorkLimitY, W_Cum, W_CumF, W_HisF.

UPDATESLEEP

APPENDIX C: Data Collection Forms and Procedures

This appendix contains the data collection forms used to structure the individual interviews and shipboard observations. Form 1 was used to gather general information about the ship and its operating characteristics. Form 2 was used to gather detailed information about individuals' work routines and the factors affecting task interruptions, sleep patterns, and fatigue. Form 3 was used to catalog the task data during the individual interviews. Each person estimated the task parameters for those tasks which they performed. Form 4 was used to structure observations of crew members' daily activities. Together, the data from these forms provided the basis for CSEM validation and analysis.

SHIPBOARD WORK/REST SCHEDULING PROJECT

FORM 1: GENERAL INFORMATION

Company: ____________________ **Ship Name:** ____________________

Researcher: ____________________ **Date:** ___/___/___

A. Ship Characteristics

1. Ship Type:

❑ Crude tanker ❑ Product carrier ❑ Container ship ❑ Other _______

2. Power Plant:

❑ Steam ❑ Diesel ❑ Gas-turbine ❑ Other _______

3. Speed

Sea speed (knts) _______

4. Size:

Length (ft.) _______

Deadweight (GT) _______ Cargo capacity (bbls/containers/tons) _______

5. Age:

Original build date _______ Date and nature of rebuild _______

6. What is the typical loading and unloading time for this ship?

Loading: _______ hrs **Unloading:** _______ hrs

B. Advanced Technology: Navigation Equipment

Name/Description	Workload Implications	Reliability Problems

C. Advanced Technology: Ship Handling Equipment

Name/Description	Workload Implications	Reliability Problems

D. Advanced Technology: Cargo Handling

Name/Description	Workload Implications	Reliability Problems

E. Advanced Technology: Engine Room

Name/Description	Workload Implications	Reliability Problems

F. Advanced Technology: Mooring and Docking

Name/Description	Workload Implications	Reliability Problems

G. General Shipboard Activities and Work Scheduling

For maintenance and repairs that could be done on board (not including shipyard repairs):

1. **How is routine, or preventive maintenance divided between shore-based, normal crew, and riding crews?**
   Shore-based ____% Normal crew ____% Riding crew ____%
2. **How are unscheduled repairs, or corrective maintenance, divided between shore-based, normal crew, and riding crews?**
   Shore-based ____% Normal crew ____% Riding crew ____%
3. **How is the total maintenance divided between preventive maintenance and repairs?**
   Preventive maintenance ____% Repairs ____%
4. **How is the engine room manned?**
   ❑ Continuous ❑ Day only ❑ Unmanned

H. Current Auxiliary Crew

Crew Type	Function	Number
Shore Maintenance		
Riding Crew		
Loading Mate		
Other		

I. Route

1. **Would you characterize this ship's route as coastwise or ocean going?**
   ❑ Coastwise ❑ Ocean going

   Description

2. **Would you characterize this ship's route as variable or fixed?**

❑ Variable ❑ Fixed

Description

3. **How many port calls are you likely to make in 3 weeks?** ________

4. **Could you provide a summary of the time spent in port, restricted waters, and open waters from that port until your last port?**

   If No, **Could you provide a summary of time spent in port, restricted waters, and open waters during a typical 3-week period?**

Route Timeline	Port 1:__________			Open Waters	Port 2:__________			Open Waters
Phase	RW	Port	RW	OW	RW	Port	RW	OW
Time (hours/days)								

Route Timeline	Port 3:__________			Open Waters	Port 4:__________			Open Waters
Phase	RW	Port	RW	OW	RW	Port	RW	OW
Time (hours/days)								

Route Timeline	Port 5:__________			Open Waters	Port 6:__________			Open Waters
Phase	RW	Port	RW	OW	RW	Port	RW	OW
Time (hours/days)								

Route Timeline	Port 7:__________			Open Waters	Port 8:__________			Open Waters
Phase	RW	Port	RW	OW	RW	Port	RW	OW
Time (hours/days)								

SHIPBOARD WORK/REST SCHEDULING PROJECT

FORM 2: INDIVIDUAL CREW MEMBER INFORMATION

Company: ____________________ **Ship Name:** ______________________________

Crew Member ID: _____-______-_____ **Crew Position** (explain): ______________________

Researcher: ____________________

Interview Duration

Session 1: Start: _______________ Stop: __________________

Session 2: Start _______________ Stop: __________________

A. Introduction

1. **How long have you been working for this company?** (total time in years or tours) ________ ❒ years ________ ❒ tours ________ ❒ days
2. **What is the total time that you have you been with this ship?** (total time in years or tours) ________ ❒ years ________ ❒ tours ________ ❒ days
3. **How long is a typical tour for you?** ________ days
4. **How many tours do you do each year?** ________ tours
5. **Do you hold a license/rating that qualifies you for a higher position (e.g., AB with a Mates license)?** ❒ Yes ❒ No
6. **Are you a permanent member of the ship's crew?** ❒ Yes ❒ No
7. **How well do you know your immediate coworkers?**
   ❒ not at all ❒ somewhat ❒ fairly well ❒ very well
8. **How familiar are you with the ship's equipment and procedures?**
   ❒ not at all ❒ somewhat ❒ fairly well ❒ very well
9. **For the ship as a whole, how would you evaluate the level of safety?**
   ❒ very poor ❒ poor ❒ average ❒ above average ❒ excellent

B. Open Waters Schedule

1. **Could you describe your typical 24-hour schedule, indicating the times for meals, regular work, overtime work, recreation, and sleep periods?**

Breakfast (B), Lunch (L), and Dinner (D)

	0000 midnight	0200	0400	0600	0800	1000	1200 noon	1400 2 pm	1600 4 pm	1800 6 pm	2000 8 pm	2200 10 pm	2359
Meals													
Work													
OT													
Rec													
Sleep													

Comments:

2. Please describe your activities and tasks for each work period during a typical day in open waters:	
Activity	Duration
Regular work period/watch	
Overtime	

3. What would disrupt this schedule?:
Meals
Regular work period/watch
Overtime
Recreation
Sleep

C. Arrival Preparation Schedule (24 hours preceding all hands call for docking)

1. Is your schedule during arrival preparation different in any way from your schedule in open waters?

❒ Yes ❒ No

If No, go to Port Schedule; If Yes continue

I would like you to pick a typical port that you go to regularly and use that as an example while answering this portion of the interview. What port would that be?_________________________

2. For arrival preparation, please describe how your activities might differ from a typical day in open waters.	
Activity	Duration
24 hours prior to all hands call - Arrival at sea buoy	
Arrival at sea buoy - All hands call	

D. In Port Schedule

1. **Is your schedule in port different in any way from your schedule in open waters?**
   ❒ Yes ❒ No
   If No, go to Departure Schedule; If Yes continue

Let's continue with the typical port that you selected as an example in the last section.

2. **For the time in port, please describe how your schedule and activities might differ from a typical day in open waters.**	
Activity	Duration
All hands call - Ship secured	
Ship secured - Start of cargo ops	
Start of cargo ops - End of cargo ops	
End of cargo ops - Last line	

E. Departure Schedule

1. **Is your schedule during departure different in any way from your schedule in open waters?**
   ❒ Yes ❒ No
   If No, go to Section F; If Yes continue

2. **For departure, please describe how your schedule and activities might differ from a typical day in open waters.**	
Activity	Duration
Last line - Sea buoy	
Sea buoy - 24 hours after departure	

F. General Factors Affecting Shipboard Activities

1. **Do you always work your watch or regular work period?** ❒ Yes ❒ No

   If No, **Under what conditions would you not work your regular work period?**

2. **Do you ever extend your watch or regular work period to finish a task?** ❒ Yes ❒ No

   If Yes, **What tasks would cause you to work longer?**

3. **How much would your watch or regular work period be extended to finish a task?** ______ hrs

4. **Do you always work your scheduled overtime?** ❒ Yes ❒ No ❒ N/A

   If No, **Under what conditions do you not work your scheduled overtime?**

5. **Do you ever work longer than your scheduled overtime to finish a task?** ❒ Yes ❒ No ❒ N/A

   If Yes, **What tasks would cause you to work longer than your scheduled overtime?**

6. **How much would your overtime be extended to finish a task?** ______ hrs

7. **If your work period coincides with the normal meal time, do you eat a meal?**

   ❒ Yes ❒ No ❒ Sometimes

   If Yes or Sometimes **How do you arrange eating your meal?**

   ❒ Relief from watch ❒ Eat quickly before watch
   ❒ Crew's meal rescheduled ❒ Other: ____________________

8. **How often are you awoken unexpectedly to work?** ______ times per ❒ week ❒ month ❒ tour

9. **What tasks or activities cause you to be awoken unexpectedly?**

10. **After having been awoken, how long would you work?** ______ hrs

11. **How often are your scheduled sleep times changed by work that you expect?** _______ times per ❒ week ❒ month ❒ tour

12. **What tasks or activities change your scheduled sleep times?**

    (specify task or activity)

13. **When work or activities change your sleep times, how long are you** ______ hrs

called upon to work?

14. How do the following affect your activities?

Weather:

Amount of cargo (loaded or empty):

Number of days between ports:

Other:

15. How often are you interrupted in performing a task?

______ times per ☐ hour ☐ day ☐ week ☐ month ☐ tour

16. What tasks are interrupted?

17. What interrupts your performance of tasks?

☐ More important tasks
☐ Supervisor changes priorities
☐ Help coworker
☐ Go off-duty
☐ Meals
☐ Other: ____________________
☐ Weather

18. Do you have enough time to get everything done? ☐ Yes ☐ No

If No, What task or tasks do you not have enough time to complete?

If No, How do you deal with your lack of time?

☐ Do the task faster
☐ Have the next shift finish the task
☐ Leave the work undone
☐ Other:
☐ Do the task later myself
☐ Go to my supervisor
☐ Delegate the work to others

19. If you could add one more person to the crew what position would this person hold?

20. What tasks and responsibilities would this person have?

G. Distribution of sleep and work

1. **What is the typical number of hours that you work per day?** _____ hrs

2. **What is the maximum number of hours you work per day?** _____ hrs

3. **How many days during a tour do you work for:**

   ______ 8 hours or less
   ______ 8 > < 12
   ______ 12 > < 16
   ______ More than 16 hours

   Total equals number of days in a typical tour ______

4. **If you ever work less than 8 hours, what is the cause of this?**

5. **What would cause you to work more than 12 hours?**

   - ❒ Mechanical problems
   - ❒ Request by supervisors
   - ❒ Change in ship's schedule
   - ❒ Training others
   - ❒ Cargo Operations
   - ❒ Weather
   - ❒ Insufficient time to complete task
   - ❒ Inspection
   - ❒ Illness of others
   - ❒ Other: ____________________

6. **What is the typical number of hours you sleep each day?** ______ hrs

7. **Ideally, how many hours would you like to sleep each day?** ______ hrs

8. **How many days during a tour do you sleep:**

   ______ 2 hours or less
   ______ 2 > < 5
   ______ 5 > < 8
   ______ More than 8 hours

   Total equals number of days in a typical tour ______

H. Effects of Fatigue with Your Current Schedule

1. **How does fatigue affect your job performance?**

2. **Which tasks are most affected by fatigue and how are they affected?**
   (specify task or activity)

4. **Have you ever had difficulty staying awake while working?** ❐ Yes ❐ No
   If Yes, **Which tasks were you performing**

5. **How often do you have difficulty staying awake while working?**
   ______ times per ❐ day ❐ week ❐ month ❐ tour

I. Effects of Fatigue Over Your Career

1. **Has fatigue ever put you in a critical situation?**

   Explain situation:

   What was individual's action/decision/inaction:

2. **Have you ever noticed a situation where someone other than you was put in a critical situation due to fatigue?**

   Explain situation:

   What was individual's action/decision/inaction:

3. **Overall do you think fatigue is a problem in the maritime industry? Why?**

4. **What do you think can be done about it?**

SHIPBOARD WORK/REST SCHEDULING PROJECT

FORM 3: TASK PERFORMANCE INFORMATION

INTERVIEW REFERENCE SHEET

NOTE: This reference sheet is intended to be used to collect task-specific information pertinent to each phase of a typical voyage (Port, RW, and OW). When a specific phase should be identified by the researcher, *PHASE*, is written in the reference sheet.

Superordinate Heading	Subordinate Heading	Question
You Perform	Yes/No	Do you ever perform this task in *PHASE*? **If Yes, mark "X" on task summary and continue** **If No, go to next task**
Performance Different from OW and Other Phase	Yes/No	*Do not ask for Open Waters:* Is your performance of this task (number of people, different frequency, different length) in *PHASE* different from your performance in Open Waters and (remaining *PHASE*)? **If Yes, complete task mark "X" on task summary** **If No, mark "S" on task summary**
After completing the task summary sheet For each task marked with an "X" complete the following		
Superordinate Heading	**Subordinate Heading**	**Question**
Duration	Avg	On the average, how long does it take you to perform this task in *PHASE*? **Alternate: how much of your time do you spend each time**
	Min	What is the minimum amount of time required for you to perform this task in *PHASE*? **See alternate above**
	Max	What is the maximum time required for you to perform this task in *PHASE*? **See alternate above**
Frequency	Avg-Per	On the average, how frequently do you perform this task in *PHASE*?
	Min-Per	What is the minimum frequency with which you perform this task in *PHASE*?
	Max-Per	What is the maximum frequency with which you perform this task in *PHASE*?

Watchkeeping Requirements	Watch Required	Is this a task that is required to be performed by a crew member who is standing a designated watch during *PHASE* operations?
	Watch Optional	Is this a task that could be performed by a watchstanding crew member if they are not otherwise assigned to a task during *PHASE* operations?
	Non-watch	Is this a task that is performed by someone other than a crew member on a designated watch during *PHASE* operations?
Priority	High	Is this a high-priority task that is central to the mission of the ship during *PHASE* operations --for example, running the ship and delivering its cargo safely and efficiently for a cargo ship?
	Medium	Is this a medium-priority task that directly supports the mission of the ship during *PHASE* operations?
	Low	Is this a low-priority task that indirectly supports the mission of the ship during *PHASE* operations?
Delay Performance	Yes/No	Can performance of this task typically be delayed during *PHASE* operations if some other, higher-priority, non-emergency task must be performed?
Interruptible	Yes/No	One performance of this task has commenced, can performance be interrupted by other, non-emergency tasks during *PHASE* operations?
Crew Pool Questions	The following series of questions are intended to identify groups of crew members who can provide equivalent functions in the performance of a task. For example, we would assume that navigation watchkeeping can, generally, be performed by all deck officer mates; or a lookout can be performed by all Able-bodied seamen.	
Pool #1	Crew members	What is one group of crew members who can provide equivalent functions in performing this task in *PHASE* operations? (identify positions of each)
	Total crew time	You have estimated that, on the average, this task requires XX (hours/mins) to perform. Would one person from this group of crew members perform this task for that period? Would one crew member spend less than this amount of time (if so, how much)? Would more than one crew member work on this task (if so, how much total time)?
Pool #2	Crew members	Is there another group of crew members who also provide a different, but equivalent, function in performing this task in *PHASE* operations? (identify positions of each)
	Total crew time	see above
Pool #3	Crew members	see above
	Total crew time	see above
Pool #4	Crew members	see above
	Total crew time	see above

SHIPBOARD WORK/REST SCHEDULING PROJECT

FORM 4: TIMELINE OF ACTIVITIES

Company: ____________________ **Ship Name:** ____________________________________

Crew Member ID: ______-______-____ **Crew Position:** ____________________________________

Researcher: ____________________ **Voyage Phase:** ❐ Port ❐ Restricted waters ❐ Open waters

Time	Activity*	Initiating event	Task	Co-workers involved
midnight 0000				
15				
30				
45				
0100				
15				
30				
45				
0200				
15				
30				
45				
0300				
15				
30				
45				
0400				

Time	Activity*	Initiating event	Task	Co-workers involved
0400				
15				
30				
45				
0500				
15				
30				
45				
0600				
15				
30				
45				
0700				
15				
30				
45				
0800				

* Key:		Activity
M	=	Meal
W	=	Regular Work/Watch
OT	=	Overtime
R	=	Recreation
S	=	Sleep

APPENDIX D: Detailed Validation and Sensitivity Analysis Results

This appendix contains detailed information used in the validation and sensitivity analysis. The first four tables show the detailed data concerning those factors that disrupt work schedules. This information played an important role in the conceptual validation of CSEM. The final tables show the high and low workload tasks used in the sensitivity analysis.

Table 1. Factors disrupting work schedules for deck crew on tankers.

Factors	Not Work Watch	Extend Watch	Not Work Overtime	Extend Overtime	Awoken Unexpectedly	Change Sleep Times
Arrival/Departure		4			4	23
Mechanical/Electrical problems		1		2	6	
Emergency	1				8	
Cargo-related activities		4			4	4
Taking on stores/Provisioning					1	
Steward dept./Clean-up		1				
Drills						3
Administrative tasks/ Paperwork		1				
Crew grievances						
Finishing tasks so that others may being working		1		4		
Overtime schedule/Budget varies			2			
Weather			2		6	3
Noise					1	
Vessel traffic		2			4	
Change in watch schedule	3					
Going ashore	2					
Recovery from previous day's work	3		3			
Illness/Fatigue/Nap/Insomnia/ General health	1		2			
Sunday/Weekends/Prefer not to work			4			
Other		3				

Table 2. Factors disrupting work schedules for deck crew on freighters.

Factors	Not Work Watch	Extend Watch	Not Work Overtime	Extend Overtime	Awoken Unexpectedly	Change Sleep Times
Arrival/Departure		4			1	16
Mechanical/Electrical problems		2		2	2	
Emergency				4	5	
Cargo-related activities					1	2
Taking on stores/Provisioning						
Steward dept./Clean-up						
Drills						2
Administrative tasks/ Paperwork		5				
Crew grievances						
Finishing tasks so that others may being working						
Overtime schedule/Budget varies			3			
Weather					1	1
Noise					1	
Vessel traffic		2			2	
Change in watch schedule	2					
Going ashore	2					
Recovery from previous day's work	1					
Illness/Fatigue/Nap/Insomnia/ General health	1					
Sunday/Weekends/Prefer not to work						
Other		2				

Table 3. Factors disrupting work schedules for engine crew on tankers.

Factors	Not Work Watch	Extend Watch	Not Work Overtime	Extend Overtime	Awoken Unexpectedly	Change Sleep Times
Arrival/Departure					2	4
Mechanical/Electrical problems		4		5	5	
Emergency	2				1	
Cargo-related activities						
Taking on stores/Provisioning						
Steward dept./Clean-up						
Drills						1
Administrative tasks/ Paperwork						
Crew grievances						
Finishing tasks so that others may being working		1				
Overtime schedule/Budget varies						
Weather						
Noise						
Vessel traffic						
Change in watch schedule						
Going ashore						
Recovery from previous day's work			1			
Illness/Fatigue/Nap/Insomnia/ General health						
Sunday/Weekends/Prefer not to work			1			
Other						

Table 4. Factors disrupting work schedules for engine crew on freighters.

Factors	Not Work Watch	Extend Watch	Not Work Overtime	Extend Overtime	Awoken Unexpectedly	Change Sleep Times
Arrival/Departure						8
Mechanical/Electrical problems		3		2	6	
Emergency					3	
Cargo-related activities						1
Taking on stores/Provisioning						
Steward dept./Clean-up						
Drills						
Administrative tasks/ Paperwork		1				
Crew grievances						
Finishing tasks so that others may being working		3		4		
Overtime schedule/Budget varies			2			
Weather			1			1
Noise					1	
Vessel traffic						
Change in watch schedule	2					
Going ashore	2					
Recovery from previous day's work						
Illness/Fatigue/Nap/Insomnia/ General health	1		1			
Sunday/Weekends/Prefer not to work						
Other						

Table 5. Person-hours of effort for tasks used in input uncertainty analysis.

Highest Workload Tasks	Hrs/Day	Cond. 2 +20%	Cond. 3 +50%	Cond. 4 +100%
12.4 Cargo Loading	45.00	54.00	67.50	90.00
12.5 Cargo Unloading	45.00	54.00	67.50	90.00
14.4 Docking	10.13	12.16	15.20	20.26
14.5 Undocking	10.13	12.16	15.20	20.26
5.3 Vessel Fabric Maintenance				
Low Workload Tasks	**Hrs/Day**	**Cond. 5 +20%**	**Cond. 6 +50%**	**Cond. 7 +100%**
10.2 Shipboard Management	0.29	0.35	0.44	0.58
11.9 Inspection Planning	0.29	0.35	0.44	0.58
12.3 Ballast Maintenance	0.29	0.35	0.44	0.58
3.1 Long Range Radio Operations	0.30	0.36	0.45	0.60
12.1 Cargo Planning	0.37	0.44	0.55	0.74

APPENDIX E: The Role of CSEM in the Certification Process: Interviews with MSO and Headquarters Personnel

Background and Objectives

Generating, interpreting, and implementing the regulations that govern crew requirements on commercial ships is a complex process that involves Coast Guard Headquarters personnel, local Coast Guard inspectors, and ship owners. The overall objective of this project is to develop tools, such as the Crew Size Evaluation Model (CSEM), to enhance the effectiveness of this process. For these tools to be effective they must consider the diverse tasks and backgrounds of the Coast Guard personnel involved. This report summarizes a series of structured interviews that investigated the crew size evaluation process within the Coast Guard. These interviews delineated the role of crew size evaluation relative to other duties, clarified the process used in crew size evaluation, and identified potential difficulties that exist in the current process. This information will help focus the development, implementation, and use of CSEM.

Approach

To better understand how the Coast Guard approaches crew size issues we conducted several brief interviews with Coast Guard Headquarters personnel and representatives from three Coast Guard marine safety offices. Although these sources do not represent a comprehensive sample, the interviews provide a relatively broad perspective of the crew size evaluation issues facing the Coast Guard.

The interviews with inspectors from the three Marine Safety Offices (MSOs) included office meetings with MSO Puget Sound and MSO Morgan City personnel and a telephone conversation with MSO Hampton Roads. Interviews addressed the following topics:

- Crew size evaluation and its relationship to other inspection duties.
- Crew size evaluation process.
- Common difficulties encountered in crew size evaluation.

The purpose of the interview questions addressing *Crew size evaluation and its relationship to other inspection duties* was to understand the role of crew size evaluation relative to the other duties and responsibilities. This has major implications for the format and complexity of any tool distributed to the MSO personnel; a complex tool that is used only infrequently is likely to cause difficulties. The purpose of the questions addressing *Crew size evaluation process* was to understand the process and strategies people currently use to conduct evaluations. Understanding the current process might identify how CSEM can enhance the resources that are already being used. The final part of the interview topic investigated *Common difficulties encountered in crew size evaluation*. Difficulties with the current process represent opportunities for CSEM to enhance the evaluation process.

The interviews with Coast Guard Headquarters personnel focused on the role of Headquarters in the crew size evaluation process. These interviews touched on how Headquarters personnel interact with inspectors and how they plan for and react to changes in commercial maritime operations. These conversations complement the information gathered from the MSO representatives and help illuminate issues associated with crew requirements throughout the Coast Guard.

Findings

Although each MSO has several unique characteristics, several important commonalties emerged. Inspectors from all three MSOs described the role of crew size evaluation as minimal in comparison to their other duties; crew size evaluation consumes no more than five percent of their effort. The inspectors rely on a variety of resources to support the crew size evaluation process; no single source addresses all issues. The complexity of the task, multiple reference sources, and limited training make for difficulties in interpreting crew requirements. The following paragraphs summarize the detailed findings, some of which are specific to particular inspectors, while others represent common themes shared by inspectors from several MSOs.

Crew Size Evaluation and Other Inspection Duties

The finding that evaluating crew requirements is a minor responsibility for OCMIs emerged as a very consistent finding across all three MSOs. Inspectors from all three MSOs reported the crew size issues consumed less than five percent of all staff time. Other responsibilities include construction design reviews, construction material reviews, and training reviews. Reviews and inspections cover all aspects of the ship, including construction, subdivision, lighting, and wiring. Most crew size issues arise only when granting a COI and are a minimal consideration during yearly inspections.

The number and type of crew evaluations vary considerably, both within and between MSOs. For example, in a typical year inspectors at MSO Morgan City review crew requirements and award COIs to 50 new vessels. Approximately 45 of these vessels are off-shore platform supply vessels, and three to five are new platforms or other large vessels. A standard crew requirement applies to these smaller vessels with few exceptions. Some of the platforms employ standard designs and require only limited review. However, a new "tension leg platform" has been under design recently that required extensive analysis and Headquarters involvement. In the past few years, a few casino boats have also been built. These require a relatively large review effort, since the vessels are large and designed to carry many passengers. (It should be noted that most of these did not go into operation after construction.) River tugs are not inspected and crew size issues with these vessels are handled primarily by Port Operations.

In contrast to Morgan City, inspectors at MSO Hampton Roads reported almost no involvement in crew size evaluation in the past year. The lack of new construction or major modifications has minimized the need to grant COIs; however, a Sealift conversion is planned in the coming year and it will require an analysis of crew requirements. Inspectors at MSO Hampton Roads have some tangential involvement in crew requirements during the inspection of over 200 vessels a year. As part of flag state control, they inspect vessels to verify that the crew meets the requirements of the COI. Likewise, the port state control responsibilities involve checking compliance with the IMO safe manning certificate during the boarding of 19 percent of the 2,000 arrivals, about 400 boardings. Neither inspections nor boardings require evaluation of the crew size, only comparison of the current crew to the crew required by the COI or IMO certificate.

Local trade and geography influence the activities at MSO Puget Sound, just as they do at MSO Hampton Roads and Morgan City. A recent effort to standardize crew requirements of "T" boats (small passenger vessels) involved a substantial effort. The wide range of size and operation makes the certification of "T" boats challenging. For example, the complexity of the engineering plant can vary dramatically; some have one machinery space and others have two or three. In some cases, the complexity may necessitate a Chief Engineer. In addition, some "T" boats may operate within the city on Lake Washington and others may travel to Alaska. The large variety in this class of vessels makes their evaluation much more time consuming. In contrast, deep draft vessels have a longer history and more consistent crew requirements.

Crew Size Evaluation Process

Several circumstances can motivate evaluation of crew requirements, including new vessel construction, public complaint, a casualty, or a major modification. A major modification might include expanded trade route, reconfiguration, or a transition from an uninspected to an inspected vessel. The most common reason for an evaluation is as part of the COI process for a new construction or a major modification. As part of granting the COI, crew size evaluation is one of many considerations and is a small part of the overall process.

When asked to describe the evaluation process, inspectors related two general cases: routine and non-routine. In the routine case, reviews are conducted by reference to standards. Coast Guard personnel match vessel and route characteristics to those contained in the standards to determine if the proposed crew is acceptable. The standards include files of previous certifications; condensed guidelines, such as the "New Orleans CID Memos" (Memo #57 has 8 pages that serve as the primary reference); Headquarters policy, as outlined in the NVICs; the marine safety manual; 46 CFR; and the U.S. Code. Specifically, the vessel size and planned routes are often reviewed and compared to certifications of previous ships to determine if the proposed crew is acceptable. These comparisons are verified against guidelines in the MSM. The U.S. Code and 46 CFR are also consulted as needed. In applying these standards, some try to avoid 46 CFR because it is difficult to use, preferring to consult the less formal sources, such as the New Orleans CID Memo #57 and a job aid for required licenses– also from MSO New Orleans– that provides practical information in an easily accessible format. A match between the proposed crew and these standards is the primary criterion used in evaluating crew requirements.

While the standards provide the primary criteria for a manning determination, several other considerations may apply. These considerations include:

- Voyage characteristics, such as frequency of port calls.
- Level of automation, such as the use of manual or automated burners.
- Reliability of automated equipment.
- Complexity of the engineering system.
- Availability of labor-saving mooring equipment.
- Passenger safety and the ability of the crew to monitor passengers and respond to passenger-related emergency.
- Emergency response, such as a galley fire, evaluated on a reasonable worst case.
- Ability to abandon ship, particularly the ability to launch the lifeboats.

Many of these considerations have no clear decision criteria and require expert judgment. Therefore, more experienced (second tour) inspectors are often called upon to review decisions.

Cases that do not fit within this routine process may require a more complex process and a greater amount of expert judgment. The "Tension Leg Platform" is a non-routine example. Here, the company proposed a crew level. Based on this proposal, the OCMI has the responsibility to review the proposal and make a determination. Because of the unusual nature of the design, Headquarters personnel were asked to get involved in some of the engineering analyses associated with the ballast and safety programs, but not on crew size. A determination of crew size was made and the owner/operator requested further reductions, which were negotiated. For most routine cases all the work is done within the department; however, the Captain of the MSO may get involved with controversial or high-profile cases. For example, in Morgan City the Captain was involved with the casino boats that had a high level of visibility. In other non-routine cases, personnel from one MSO may contact another MSO that has addressed a similar issue. In addition, they may solicit aid from Headquarters either formally or informally. Headquarters personnel are seldom formally involved except for new/radical designs, such as the TLP or a quadmaran (a four hull vessel).

A key element in the process is the involvement of the ship owners. Ship owners provide the OCMI with a proposal that typically includes:

- Route/area of operation, such as the distance from the nearest safe harbor.
- Duration of trips, including the time away from port in a 24-hour period.

- General operational restrictions, such as the maximum number of passengers.
- Ship design, such as the general ship dimensions and detailed engineering specifications and drawings.
- Proposed crew level, including the number of each crew type.

In general, the inspectors agreed that coordination with ship owners is quite good. In several instances they have noticed a tension between safety and economics. Specifically, a TLP owner created some contention by trying to reduce the crew by one operator, but this process proceeded on a "partnering" model. To further smooth communications with industry, MSO Morgan City has a streamlined inspection process for model companies.

As part of the certification, the ship undergoes sea trials. These tests require several hours of an inspector's time, but do not require an extended stay of days or weeks on the ship. During the sea trials the primary focus of attention is on the engineering and navigation system and crew requirements are not a major concern. The yearly inspections also consume a significant amount of the inspectors' time. These inspections include observation of drills and operations and may identify gross deficiencies in crew requirements if the crew is unable to launch lifeboats or conduct a fire drill effectively.

Petitions for automation-related reductions involve a year-long trial period where the automation is exercised, but the full crew is retained. At the end of the year, a positive review of the automation performance can allow the ship owner to reduce the crew. The review of the year-long trial period involves evaluation of maintenance-related overtime, informal interviews with crew members regarding overtime, records of automation-related alarms, and direct observation of vessel operations (minimum of 24 hours while underway). MSO Puget Sound and MSO Morgan City had similar comments regarding automation. They have monitored several ships that have applied for automation-related crew reductions. Over the trial year several of these vessels have experienced such reliability problems that crew members had to be added rather than removed. Thus, the reliability problems with some modern, automated equipment has the paradoxical effect of increasing manning requirements.

The inspectors see several trends in the future. They do not expect automation-related reductions to be a major factor because many vessels have already obtained all of the possible crew reductions, so inspectors expect no further reductions. The inspectors may be overlooking the potential for technological changes to challenge the fundamental standards they use to judge crew requirements. In addition, offshore platforms may request further reductions, and new technology (such as integrated bridges) might dramatically change the crew requirements. In the 8th District, the "Declaration of Pilotage Area" is a potential initiative with far-reaching impact. This initiative would increase pilotage endorsement requirements, requiring more local operators who have adequate experience on local waters. This may generate new requirements for crew members included in the COI. More generally, international safe manning requirements may affect U.S. vessels and complicate the role of the inspectors. Inspectors anticipate greater port state responsibilities and the prospect of verifying international requirements for all vessels. It is not clear how these responsibilities will change, but they are likely to depend on IMO decisions and the role of the U.S. Coast Guard in the international maritime community.

Common Difficulties Encountered in Crew Size Evaluation

Inspectors reported several difficulties with crew size analysis, including:

- Increased workload.
- Inadequate training and depth of experience.
- Difficulties coordinating with Headquarters.
- Difficulties interpreting CFRs and locating evaluation standards.
- The pace of technology change exceeds that of the standards.
- Difficult judgment calls and potential inconsistencies.

Many feel that increased workload is becoming a major problem and fear that it may be worse in the future as the Coast Guard is called upon to do more with less. The role of the Coast Guard in IMO safe manning certification and enforcement is one factor that could increase workload.

The level of training given to inspectors on issues associated with crew evaluation is quite mixed. In some cases no training is provided and people must rely on themselves to identify references and procedures. Even for those that receive substantial training, the rotation schedule leaves little cumulative experience upon which inspectors can draw.

For controversial or non-routine cases, inspectors will work with Headquarters personnel. This process seems to work very well for informal communication. Informal communication involves brief conversations with colleagues/friends to clarify confusions, while formal communication requires a more explicit position statement from Headquarters. As one might expect, informal communication often provides rapid responses, while inspectors find formal communication to involve a great amount of time and effort.

One of the largest problems is the interpretation of evaluation standards, such as the CFRs. This is particularly true in cases when there are different operations for the same vessel resulting in potentially conflicting guidelines. Other standards, such as the MSM, have been developed to resolve some of these difficulties; however, MSO personnel do not always know where to look for these standards.

These problems of locating and interpreting standards are complicated by the changing ship technology. Changes in ship equipment, and the corresponding changes in crew requirements are outpacing the changes in the standards. Without updated guidance, OCMIs are forced to make judgment calls that are not founded on extensive experience.

Interpretation difficulties and the rapidly changing technology force a number of difficult judgment calls. For example, how well will surveillance cameras on platforms substitute for in-person inspections? or does the reconfiguration of a passenger vessel allow for safe operation with one person per deck? Changing technology, the unique characteristics of vessels, and their unique operating conditions makes for difficult judgments and potential inconsistencies. For example, some crew requirements are locally defined. Morgan City and New Orleans have local standards that may differ from Florida and Texas for the number of watchmen and deck hands aboard crew boats. Whether these differences reflect operating conditions, local politics, or variability in the interpretation of standards was not known by the respondent. A similar concern motivated a major effort to reevaluate the crew requirements of many "T" boats to impose a more uniform set of requirements.

Role of Headquarters

G-MSO-1 and G-MSO-2 are the two branches within Coast Guard Headquarters that have significant involvement with issues concerning crew requirements. G-MSO-1 has the responsibility for developing long-term policy by supporting lawmaking and interpreting laws to define regulations. As part of this process, G-MSO-1 also works with the international maritime community to guide, define, and interpret IMO policies. G-MSO-2 works with G-MSO-1 to implement the regulations and broad policies developed by G-MSO-1. G-MSO-2 helps develop specific Coast Guard policies by interpreting laws, regulations, and standards. These policies are communicated through the Marine Safety Manual, NVICs, and letters of guidance. G-MSO-2 also provides a critical link between Headquarters and inspectors at the MSOs. In this role, G-MSO-2 helps evaluate complex decisions, provides policy guidance, and makes determinations on waivers and appeals. This may also involve coordinating the appeal process and supporting field operations. Overall, G-MSO-2 has the responsibility for interpreting and applying regulations to set Coast Guard policy, and for serving as a Headquarters contact point for the MSOs. Together, G-MSO-1 and G-MSO-2 develop the standards that define crew requirements and guide the decisions of the inspectors. In this way, Headquarters oversees day-to-day issues of vessel staffing and provides the long-term guidance of Coast Guard policy.

Implications for CSEM Development

These findings have several major implications for CSEM development and implementation. One set of implications concerns the inspector activities and the others concern Headquarters activities.

Implications for CSEM from Inspectors

One of the most important findings was that crew size evaluation consumes less than five percent of all staff time. This suggests inspectors will use any crew size evaluation tool very infrequently, making it difficult to learn and remain proficient in using the tool. This makes the distribution of a complex computer-based crew size evaluation tool impractical. A simple tool or a paper-based system could be practical. A computer-based tool would be particularly helpful if it could be integrated into a software package that supports other elements of the certification process, such as evaluation of structural integrity, the engineering system, or the navigation system. To our knowledge no such software tool exists. Integrating a crew size evaluation tool with tools that support other elements of the certification process would minimize the learning difficulties that might make a single-purpose piece of software impractical.

Several inspectors voiced a concern about the potentially confusing array of standards. Some of these, such as 46 CFR, are difficult to interpret and others may not be readily available. In addition, some standards are ambiguous and require judgment calls that may have little technical basis. This can result in inconsistent and inappropriate crew requirements. MSO Morgan City has developed several job aids to support the evaluation process and a similar reorganization of crew size evaluation information might be useful for other inspectors at other MSOs. Job aids that condense the various standards into a single, integrated, and practical source could greatly simplify the inspectors' task. Similarly any job aids generated by CSEM analysis should be incorporated into existing references or provide links to those references. A poorly integrated job aid would only add to the confusing array of standards that inspectors must consider during certifications.

Creating a database of certifications would be another approach to enhance the consistency between inspectors. With a database of previous certifications, the inspector could identify similar vessels and compare the previous crew requirements to the proposed crew for the new vessel. A case-based reasoning tool could perform a similar function by matching critical vessel characteristics to acceptable crew complements. Situations that do not fit within these standards may require analysis with a task-based tool such as CSEM.

Consistent with the development plan for CSEM, the variety of vessels that require certification points to the need to broaden the database beyond tankers and freighters. For a crew size analysis tool to be useful to inspectors it must apply to a broad variety of vessels. The interviews did not identify a particular type or class of vessels that are particularly troublesome. Inspectors at each MSO certify a different mix of vessels and have different needs for crew evaluation. Identifying the most critical class of vessels for task-based analysis requires the broad perspective of Coast Guard Headquarters.

The primary criterion for judging crew requirements is compliance with standards. Several comments point out that the standards do not cover all issues unambiguously. Standards leave gaps that the inspectors must fill with expert judgment. This ambiguity may lead to inconsistent and inaccurate estimates of crew requirements. Task-based analyses performed with CSEM might help fill the gaps with consistent guidelines. Thus, a combination of task-based analysis and standards may be the most efficient and effective approach to certification. The complexity of such a tool, combined with its infrequent use, will likely require consultation with Headquarters personnel.

Implications for CSEM from Headquarters Personnel

The findings also identify several implications for supporting the role of Headquarters personnel in the crew size evaluation process. The interviews suggest that Headquarters personnel support the analysis of crew requirements through three primary roles: (1) setting the long-term policy of the Coast Guard regarding crew requirements, (2) interpreting the U.S. Code and regulations to define the standards for vessel staffing, and (3) helping inspectors to resolve unusual cases. Each of these roles has implications for CSEM.

The interviews identify long-term policy development as major role of Headquarters. As part of this role, G-MSO-1 personnel help develop new laws and regulations and coordinate with IMO to define new international agreements. As technology advances and traditions evolve, the staffing standards used by the U.S and other countries will need to change. These changes may be so radical that past experience and current standards may be of little use in defining crew requirements. For these situations, CSEM may be particularly useful. CSEM could easily be used to examine many of the issues that face the Coast Guard and the international maritime community. The Coast Guard can use CSEM proactively to analyze a variety of operational scenarios to determine what factors influence crew requirements. This will help the Coast Guard meet its goal of "rationalizing" vessel staffing. For example, a component of CSEM, the task list, may provide a common language for discussing the role of different crew type and crew requirements. Thus, the task-based approach of CSEM is needed to support a careful evaluation of the effect of maritime operations on safe crew size, which will provide an objective, data-driven foundation for new laws, policies, and standards.

Another major role of Headquarters personnel is to interpret and summarize the U.S. Code and regulations into documents such as the Marine Safety Manual, NVICs, and letters of guidance. A task-based analysis tool has an important role in this process because it provides an objective and verifiable basis for resolving ambiguity and identifying crew size standards. Because the U.S. Code and regulations may allow multiple interpretations, CSEM can be used to evaluate alternatives to develop policies that are consistent with the intent of the legislation. This analysis could then be placed into reference documents, such as the MSM and NVICs, for use on a day-to-day basis by Headquarters personnel and inspectors.

The interviews suggest that inspectors call upon Headquarters personnel for consultation during unusual certifications. These situations arise because the standards (CFRs, MSM, NVICs, and other heuristics) do not always apply in a unambiguous manner. In addition, a company may request a variance to the standards. When the inspectors call upon Headquarters personnel, there may be no well-defined policy or precedent to guide decisions. This suggests a need for a flexible analysis tool that can analyze crew requirements based on tasks and duties required to safely operate the ship in a variety of scenarios. This has been the design intention for CSEM. The complexity of CSEM may preclude its use on a case-by-case basis, but planned R&D Center analyses may indicate that a simpler model, using a subset of the current task list, could be feasible for evaluating unusual cases.

The implications for CSEM derived from interviews with Headquarters personnel suggest that the objectives of CSEM are consistent with the needs of Headquarters personnel. These interviews support the premise that a flexible, task-based analysis tool is needed to adequately address the issues that Headquarters personnel face. The interviews do not clarify exactly how CSEM could support this analysis. The complexity of CSEM that is required to meet these needs may demand a substantial investment in training and, if used infrequently, users may forget how to operate the system. One potential solution to this problem would be to simplify CSEM; another would be to identify a process where Coast Guard R&D Center staff could conduct analyses for Headquarters personnel on an as-needed basis. The feasibility of model simplification will be examined as part of the planned sensitivity analysis. If the predictive ability does not suffer when the CSEM is simplified, then a less complex, easy-to-use model may be implemented to meet the needs of Headquarters personnel.

Conclusions

The interviews with inspectors and Headquarters personnel suggest that the current crew size evaluation process depends on the **application of standards** that define crew requirements. To accommodate the variety of vessels under Coast Guard jurisdiction, these standards are necessarily complex. The Coast Guard has developed a number of standards, such as NVICs and the MSM, to facilitate the interpretation and application of the U.S. Code and the CFRs. However, substantial confusion still exists and the standards are not always applied consistently. Integrating standards, developing databases of past certifications, and creating case-based expert systems could facilitate a consistent application of standards.

Standards do not apply to all situations. Currently, inspectors and Headquarters personnel must fill the gaps in the standards using expert judgment. Expert judgment that may not always provide a sound technical basis. In addition, technological change undermines the ability of the Coast Guard to develop standards based on long-standing maritime traditions. To address issues not covered by current standards and to develop new standards that accommodate fundamental changes requires a **task-based analysis**. CSEM supports a flexible task-based approach to crew size evaluation. This approach can fill the gaps in current standards. CSEM can also examine a variety of operational scenarios to support development of standards that accommodate the fundamental changes that are sweeping the maritime industry.

The interviews suggest that **application of standards** and **task-based analysis** both have an important role in the accurate and efficient evaluation of crew requirements. **Application of standards** provides a relatively simple, fast, and easily learned approach to crew evaluation. A **task-based analysis** provides a necessary complement by filling gaps in the current standards and by aiding the Coast Guard in developing standards when long-standing traditions and assumptions do not hold.